Manual of Forestry

Vol. III.

Forest Management

by

Sir Wm. Schlich, K.C.I.E.

SCHLICH'S

MANUAL OF FORESTRY.

ERRATA.

Page 56, lines 4, 5 and 6 from the top. *Eliminate the sentence beginning with* " The correctness " *and ending with* " Forestry Commission."

,, 59, line 4 from top. *For* " ·462 " *substitute* " ·47 "

,, 61, line 5 from top. *For* " 8 " *substitute* " ·8 "

,, 98, line 10 from top. *For* " one " *substitute* " the same "

,, 122, line 1 from top. *For* " — " *substitute* " = " (equal)

,, 131, line 4 from bottom. *For* " I." *substitute* " III."

,, 135, line 8 from bottom. *For* " $\frac{\mathbf{T_a}}{\mathbf{1{\cdot}0p}}\mathbf{a}$ " *substitute* " $\frac{\mathbf{T_z}}{\mathbf{1{\cdot}0p^a}}$ "

,, 219, line 2 from top. *For* " $V_r + 1$ " *substitute* " V_{r+1} "

,, 261, line 15 from bottom. *Add* " a " *at the end of the line*

,, 312, line 8 from top. *For* " 122 " *substitute* " 124 "

,, 312, line 1 from bottom. *For* " 7,072,640 " *substitute* " 7,022,640 "

,, 313, line 2 from top. *For* " 707,264 " *substitute* " 702,264 "

,, 313, line 3 from top. *After* " Appendix V." *add* ", page 368 "

,, 313, line 13 from bottom. *Eliminate* " natural "

SCHLICH'S MANUAL OF FORESTRY.

VOLUME III.

FOREST MANAGEMENT,

INCLUDING

MENSURATION AND VALUATION.

BY

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AND LATE PROFESSOR OF FORESTRY AT OXFORD.

FIFTH EDITION.

Revised, and the greater part rewritten.

WITH 68 ILLUSTRATIONS.

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1925.

In former editions of this volume, numerous references were given to matters dealt with in Volume II., Silviculture. This has been found to be somewhat inconvenient, and the practice has, as far as possible, been abandoned. It has been obviated by giving, in connection with the Determination of the Yield, short accounts of the various silvicultural systems (with a few illustrations from Volume II.).

The manuscript of the present edition has been read by Mr. C. E. C. Fischer, Conservator of Forests, Madras, on leave, and the proofs from the press have been examined by my daughter, Miss Schlich. I am greatly indebted to them for their help.

W. SCHLICH.

Oxford, *January* 20, 1925.

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FOREST MANAGEMENT.

INTRODUCTION.

The management of forests depends, apart from local conditions, on the objects which it is proposed to realise. These differ considerably according to circumstances, but, whatever they may be, they can be brought under one of the following two headings :—

(1.) The realisation of indirect effects, such as landscape beauty, preservation or amelioration of the climate, regulation of moisture, prevention of erosion, landslips and avalanches, preservation of game, hygienic effects, etc.

(2.) The management of forests on economic principles, such as the production of a definite class of produce, or the greatest possible quantity of it, or the best financial results.

It rests with the owner of the forest, in so far as his choice is not limited by the laws of the country, to determine in each case what the objects of management shall be, and it then becomes the duty of the forester to see that these objects are realised to the fullest extent and in the most economic manner.

In some cases the realisation of indirect effects requires a special and distinct management, but in the majority of cases they can be produced in combination with economic working. The present volume deals chiefly with the economic aspect of forest management.

The economic working must be based on the yield of the forest. In order to determine this, the forester must study the laws which govern production ; he must be able to measure the produce and the increment accruing annually or periodically, to determine

the capital invested in the forest, to regulate the yield according to time and locality and to organise the systematic conduct of the business.

Accordingly, forest management may be divided into the following parts :—

Part I.—Forest Mensuration, dealing with the determination of the dimensions of trees, the volume of trees and whole woods, their age and increment.

,, II.—Forest Valuation, dealing with the determination of the capital employed in forestry and the financial results produced by it.

,, III.—The Foundations of Forest Management.

,, IV.—Preparation of Forest Working Plans.

This volume is chiefly destined for the use of students of forestry, and its contents are arranged accordingly. Part I., "Forest Mensuration," and Part II., "Forest Valuation," should be considered as auxiliaries to Forest Management. They contain all the matters required by the student, and they should not be compared with special works on the two subjects, such as Baur's, Graves' and Chapman's "Forest Mensurations," and Heyer's, Endres' and Chapman's "Forest Valuations." These books deal not only with the methods of measuring and calculating, but also with all kinds of applications, many of which are not connected with forest management. Students, who have assimilated what is given in this volume on the two subjects, will have no difficulty in dealing with any case which may come before them in discharging the duties of an expert forest officer. In Mensuration several methods for the measurement of standing crops have been added which were not considered necessary when the earlier editions were published, or which have been elaborated since then. Of "Forest Valuation" the greater part has been rewritten, and the chapter on the financial results of forestry has been treated from a new point of view inaugurated by the author. The Continental yield tables of spruce, Scots pine and larch have been replaced by British yield tables prepared by the Forestry Commission, and a yield table of the Indian tree "sal" (*Shorea robusta*) has been added. There are also new money yield tables of larch, spruce and Scots pine.

A great part of Management [Parts III. and IV.] has been rewritten on the basis of further experience gained since the publication of the fourth edition. Several new methods of treatment have been added, specially elaborated with the object of improving the process of regeneration and the preservation of the yield capacity of the soil. During recent years it has, more and more, been recognised that each laying bare of an area under forest has a deteriorating effect upon the sustained fertility of the soil, in all cases where the rainfall is unfavourably distributed over the seasons of the year and especially over the growing season. In such cases, drought, frost and also insects do increased damage ; more particularly, the degree of moisture in the soil is liable to be reduced below the minimum required for a healthy development of the new crop. Foresters of experience have recognised the importance of returning to the former practice of regenerating the forests under one of the shelterwood systems, whenever the quality of the soil is not of a high order and the climatic conditions unfavourable, planting and direct sowing of the seed on bare land being restricted to new afforestations, to places where natural regeneration has failed and in some cases to the cultivation of highly light-demanding and quick-growing species.

The rainfall over the greater part of the British Isles is favourably distributed, but by no means over all parts ; years like 1911 and 1921 have shown the amount of damage which can be done by a drought of some duration. Many parts of the British Colonies are less favourably situated ; in these, drought is the rule and not the exception. In such cases, the results of leaving the areas exposed to unfavourable climatic conditions are very serious ; they should, as soon as possible, be brought under efficient protection and, at any rate to begin with, managed under a simple method such as the selection system. This can by degrees be led over into the regulated selection system, which has been dealt with in full detail in Part IV. Whether, and to what extent, a more elaborate or concentrated system should ultimately be substituted may safely be left to future consideration. In India, apart from small experiments, it took 50 years of strenuous work before substantial progress with the conversion of the selection system into the compartment or uniform system could be begun ; even now the area taken in hand for that purpose is as yet a small

part of the total area of the forests under the management of the Forest Department. Besides, such conversions have yet to prove that they are the blessing for the country which their promoters expect them to be. In the Colonies, at any rate, the most important work in the immediate future is to bring the forests under efficient control, to constitute an area of permanent State forests sufficient to give a sustained yield of produce in the future, to protect them against fire and to open them out for traffic, especially by a well-considered system of roads. The next measure will be to prepare suitable working plans for the different forests, based on the principle of a sustained yield in the future, and to regulate, according to time and locality, the manner in which it is to be realised.

Important as these measures are, care should be taken to see that the prescriptions of management do not override the application of sound silvicultural principles. Management should be the servant and not the master of silviculture. It is the business of the latter to provide the conditions for the most favourable development of forest growth, of which the maintenance, if not the increase, of the fertility of the soil is the most important.

PART I.

FOREST MENSURATION.

FOREST MENSURATION.

Forest Mensuration deals with the determination of the dimensions, volume, age and increment of single trees and whole woods.

The data thus obtained are required for the calculation of the material standing on a given area, the yield which a wood can give, the value of single trees, woods and whole forests. They serve also as the basis for the determination of the comparative value of different species and methods of treatment of woods, as well as for the calculation of the financial results of forestry generally.

The matter dealt with in Part I. has been divided into the following chapters :—

Chapter I.—Instruments used in Forest Mensuration.
,, II.—The Measurement of Felled Trees.
,, III.—The Measurement of Standing Trees.
,, IV.—The Measurement of Whole Woods.
,, V.—Determination of the Age of Single Trees and Whole Woods.
,, VI.—Determination of the Increment of Single Trees and Whole Woods.

The units of measurement of dimensions and volume are the British foot, square foot and cubic foot.

CHAPTER I.

INSTRUMENTS USED IN FOREST MENSURATION.

Instruments are required to measure the circumference or diameter of logs and trees, the length of logs, the height of trees and the increment, for the purpose of ascertaining these dimensions and to calculate from them the volume of the measured object. In the latter case, the area of the cross-cut section is calculated on the assumption that it forms a circle. It is called the " sectional " or " basal " area.

1. Instruments for the Measurement of the Girth.

The girth may be measured with a tape, or with a string and a tape. The latter consists of a band about half an inch broad, so constructed that it alters its length as little as possible when wet. It is divided, on one side, into feet, inches and, if necessary, parts of an inch ; on the other side the sectional area corresponding to the girth may be marked, or the quarter girth. It is useful to have a small hook at one end, which can be pressed into the bark when the girth exceeds 5 feet. Long tapes are rolled up in cases, which are made of leather, wood, or metal. Flexible steel tapes have come much into use. The advantages of the tape are that it is easy to handle and to carry. Measurements with it are, however, subject to various sources of inaccuracy, amongst which the following should be mentioned :—

(*a*) As the cross-sections of trees generally differ in shape from that of a circle, the calculation of the basal area calculated from the girth is liable to be incorrect.

(*b*) Owing to the presence of rough bark, the measured girth is too long.

(*c*) The tape is frequently not applied at right angles to the axis of the tree.

In order to avoid some of the disadvantages, the girth is sometimes measured with a thin string, which is then held parallel to a graduated tape. In this way more accurate results may be obtained, but the operation takes more time, and it is, therefore, uneconomic to employ it where large numbers of trees are to be measured.

2. Instruments for the Measurement of the Diameter.

The diameter of cross-sections of felled trees is measured with an ordinary rule or a tape ; in other cases, the calliper is used, or sometimes the tree compass.

a. The Calliper, or Diameter Gauge.

The number of differently constructed callipers, as well as of other forest instruments, is very large, and it would take much

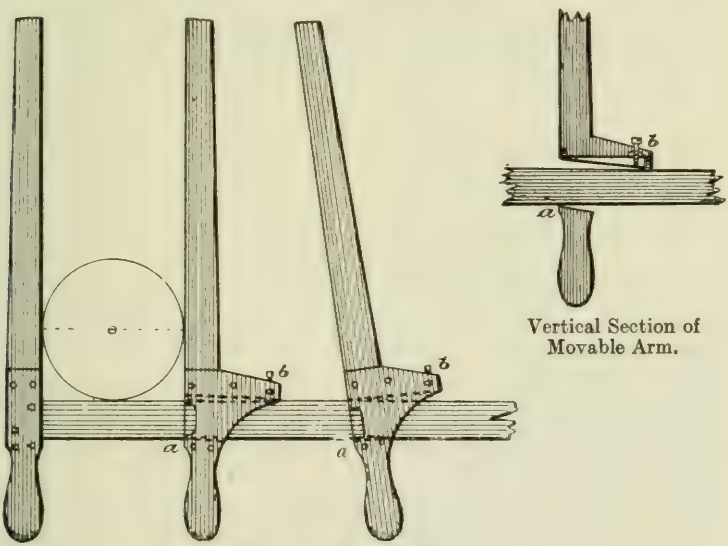


Fig. 1.—Friedrich's Calliper.

space to describe them all ; nor is it necessary to do so, as only comparatively few are of real practical use. Some of the latter kinds have been chosen to illustrate the theory in each case ; the actual value of the various instruments must be estimated by using them in the forest.

The calliper consists of a graduated rule and two arms. Of the latter, one is fixed at right angles to one end of the rule, so that its inner plane lies in the starting point of the graduated scale ; the other arm moves along the rule parallel to the fixed arm. In using the calliper, the tree is brought between the two arms, so that it touches the rule ; then the fixed arm is pressed against the tree on one side and the movable arm shifted until it touches the

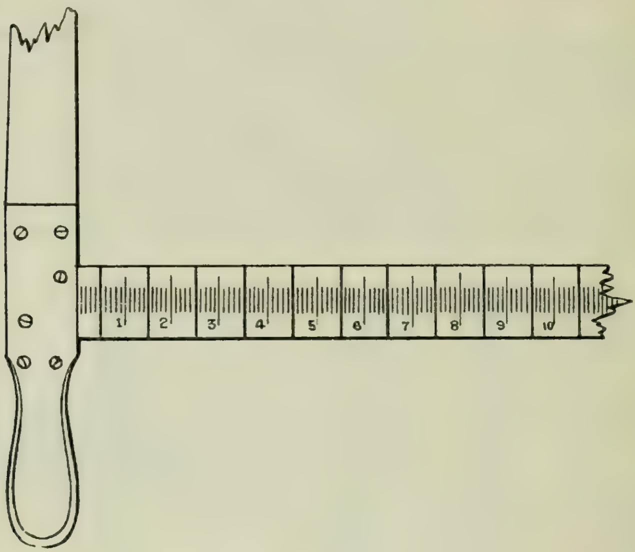


Fig. 2.

tree on the other side. The diameter can then be read off on the rule.

The length of the rule and of the arms depends on the size of the trees to be measured ; each arm should be at least half the length of the rule. Callipers exceeding 4 feet in length are rarely used. The rule is divided into units, the size of which depends on the desired degree of accuracy. Ordinarily, they will be half inches, inches, or two inches, and, for very accurate measurements, decimals of inches. When large numbers of trees are to be measured, it is desirable to round off the limits of each unit ; for instance, if the rule is divided into inches, the first division line is placed at $\frac{1}{2}$ inch from zero, the second at $1\frac{1}{2}$ inches, the third at $2\frac{1}{2}$, and so on (Fig. 2). In this way, all trees measuring from

$\frac{1}{2}$ to $1\frac{1}{2}$ inches are recorded as having a diameter of 1 inch, those from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches as 2 inches, and so on.

A good calliper must fulfil the following conditions :—

(1.) It must be sufficiently light so as not to fatigue the labourer and yet sufficiently strong to resist the wear and tear to which it is likely to be subjected.

(2.) The two arms must be at right angles to the rule or at least parallel to each other when pressed on to the tree.

(3.) The movable arm must move with sufficient ease along the rule and yet not be too loose.

Callipers of iron would be too heavy and too cold in winter; the former objection can be removed by making them of aluminium. Hitherto, callipers have generally been made of wood, although, with changes in the degree of humidity, the movable arm is liable to jam at one time or to move too easily at others. To avoid this drawback, various constructions have been adopted, resulting in a number of callipers of which the following deserve to be mentioned :—

Gustav Heyer's Calliper.—The distinguishing feature of this instrument is that the rule is given, in section, the shape of a trapezium, and that it is pressed up or down in the movable arm by means of a wedge, so as to counteract the swelling or shrinking of the wood. In Fig. 3, *a* represents the cross-section of the rule, *b* the wedge, *c* the section of the movable arm. The wedge is fastened to a screw which can be moved by a key at *d*. On moving the wedge from left to right, it presses the rule upwards and thus tightens it; on moving the wedge from right to left, it releases the rule and enables the arm to move more freely. To force the rule to follow the movement of the wedge, a spring is fastened at *e* which pushes

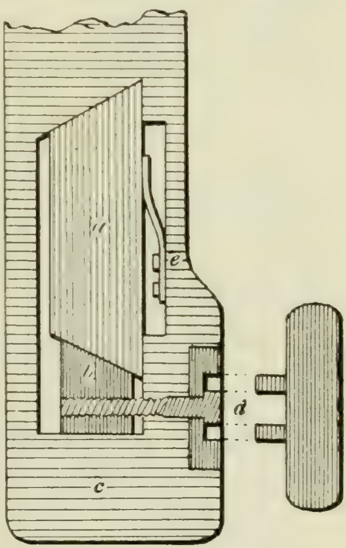


Fig. 3.—Heyer's Calliper.

it from right to left, so that it is always kept in touch with the wedge.

Friedrich's Calliper.—In this instrument the section of the rule has the shape of a rectangle, and the opening of the movable arm is larger than the section of the rule and placed slantingly towards it. At the same time, it is so shaped that, on being pressed against the tree, it assumes a position which is at right angles to the rule (see Fig. 1). In this position the arm rests on the two points *a* below and *b* above. As these points are liable to wear away, thus causing the arm to assume a position which is no longer at right angles to the rule, Boemerle has added a spring at *b* by which the true position of the arm is secured.

Callipers have been designed which enumerate the number and classes of trees, and others which give their basal area. The construction is, in several cases, very ingenious, but they are generally very heavy, so that the labourer rapidly tires ; nor are these instruments always free from inaccuracies. They cannot be recommended for use in practical forestry ; hence it is not proposed to deal with them in this place.

b. *Accuracy of Measurement with the Calliper.*

To secure the greatest possible accuracy, the following precautions must be taken :—

(1.) Moss, creepers, etc., found on the tree must be removed before measurement.

(2.) In the case of an abnormal swelling or indenture, the measurement must be taken above or below it, or both and the average taken.

(3.) In the case of eccentric or elliptic shape of the cross-section, two diameters at right angles to each other must be measured and the mean taken.

(4.) The height fixed for the measurement must be strictly adhered to.

(5.) In the case of a tree divided into two or more limbs below the fixed height of measurement, each limb should be measured and recorded as a separate tree.

(6.) The calliper must be placed at right angles to the axis of the tree, and the rule must touch it.

(7.) The reading must be taken while the calliper rests on the tree and not after it has been withdrawn.

c. The Tree Compass.

The shape of this instrument will be seen on reference to Fig. 4. The diameter of the tree or log is taken by the two points c and d, and it can be read off at h on the arc $f g$. In order to produce sufficient stiffness in the arms of the compass, they have to be made of metal, which makes the instrument very heavy and unsuited for continued work.

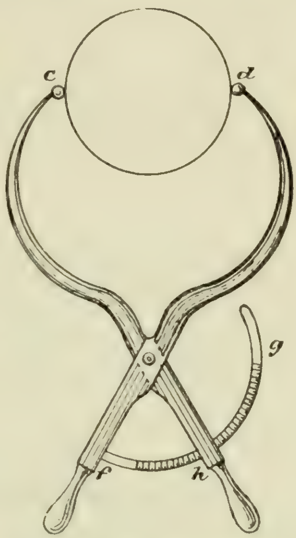


Fig. 4.—The Tree Compass.

There is a difference of opinion as to the comparative accuracy of measurement and subsequent calculations of the basal area from diameter and girth measurements. There is no doubt that the former works quicker, and, in the author's opinion, it gives more accurate results if two diameters at right angles to each other are measured.

d. Dendrometers.

In some cases dendrometers are used to measure the diameter of trees at some height from the ground. The theory is as follows : The angle which is formed by two rays running to the two sides of the tree is measured, as well as the distance of the eye of the observer from the tree. From these data the diameter at a certain height from the ground is calculated. Instead of the angle, the distance $a\,b$ between the two rays is measured and the diameter obtained in the following way (see Fig. 5 on next page) :—

$$C\,A : C\,a = A\,B : \; a\,b, \text{ and } A\,B = \frac{C\,A}{C\,a} \times a\,b.$$

If the instrument gives $a\,b$ and $C\,a$, and $C\,A$ is ascertained, the diameter at a certain height can be calculated.

$$C\,A \text{ is} = C\,D \times \textit{sin. } A\,C\,D, \text{ or} = \sqrt{C\,D^2 + A\,D^2}.$$

So far, instruments of this class have not obtained a footing in

practical forestry, because those available either do not work with sufficient accuracy or take too much time.

3. Instruments for the Measurement of the Diameter Increment.

The diameter increment of prepared sections is measured with an ordinary rule, or with a pair of compasses and a rule. If no sections are available, as in the case of standing trees, the measurements are made with Pressler's Increment Borer (Fig. 6).

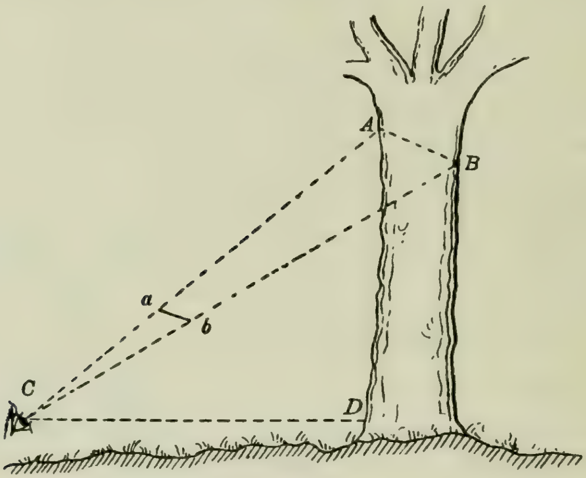


Fig. 5.

The instrument extracts a cylinder of wood from the stem, and it consists of the following parts :—

(1.) A hollow borer, *A*, which is slightly conical from the handle towards the point.

(2.) A handle, *B*, which serves as a lever when the instrument is in use. It is hollow and receives the borer, wedge and cradle when the borer is not in use (see *E* in Fig. 6).

(3.) A wedge, *C*, which has a scale marked on one side wherewith to measure the breadth of the concentric rings ; it is roughly toothed on the other side to assist in extracting the cylinder of wood.

(4.) A cradle, *D*, in which the cylinder of wood is placed after extraction, to prevent its breaking.

The borer is used in the following way : It is screwed in a radial direction into the tree, at right angles to its axis, to the desired depth, whereby a cylindrical column of wood enters the hollow borer and is severed from the tree, except at its base ; then the wedge is inserted between the column of wood and the inner wall of the borer, with its toothed side towards the former, and firmly pressed in. This prevents the cylinder of wood from turning

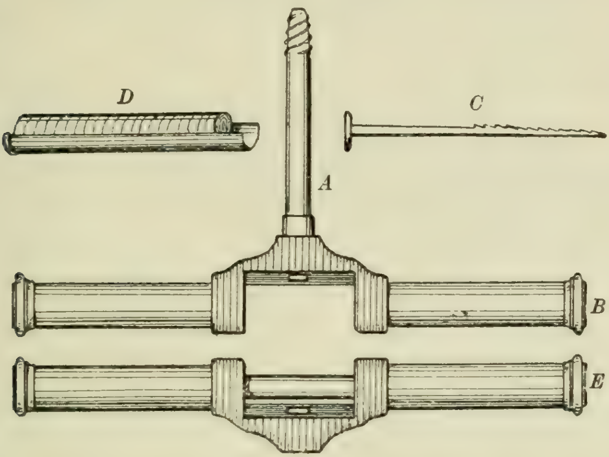


Fig. 6.—Pressler's Increment Borer.

round inside the borer ; the latter is then screwed backward one or two turns, whereby the base of the cylinder of wood is severed from the tree ; the borer is then screwed further in, which causes the severed cylinder of wood to be pushed back until it can easily be withdrawn and placed in the cradle. In this way, a column of wood about 0·2 inch in diameter and up to 6 inches in length is obtained, on which the breadth of the desired number of concentric rings can be measured. If the rings are not distinct, a smooth surface can be prepared with a sharp knife.

4. Instruments for the Measurement of the Length of Felled Trees and Logs.

The usual instruments are a tape or a measuring staff. The latter may be of varying length, say, up to 15 feet. It should be made of hard, straight-grained, well-seasoned wood and varnished

to protect it against moisture ; the ends may usefully be capped with iron plates.

5. Instruments for the Measurement of the Height of Standing Trees.

The instruments which have been designed for the measurement of the height of standing trees are very numerous ; they may be divided into two classes, geometrical and trigonometrical height measurers.

a. Geometrical Height Measuring.

If a horizontal plane is drawn from the eye of the observer to a tree, it will hit the same, according to the position of the observer,

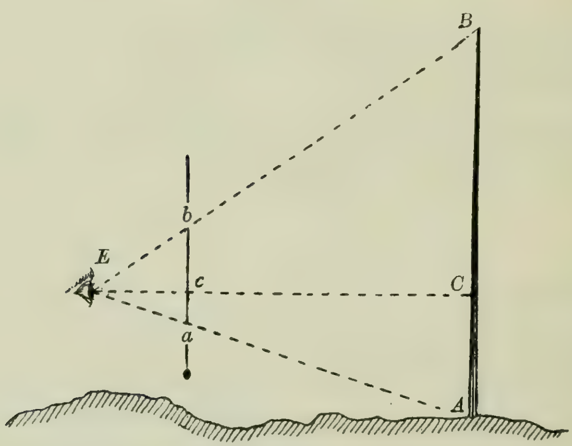


Fig. 7.

either between the top and foot thus dividing it into two parts, one of which is situated above and the other below the horizontal plane, or above the top or below the foot of the tree. In either of these cases similar triangles are formed which are used for the determination of the height of the tree (Fig. 7). Let *A B* be the height of the tree ; *E B* a ray from the eye of the observer to the top of the tree ; *E A* a ray from the eye of the observer to the foot of the tree ; *E C* a horizontal ray ; *a*, *b*, and *c* the points

where the three rays hit the plumb-line ; then the height of the tree is determined as follows :—

(1.) The horizontal line hits the tree between the top and the foot, when the following equation holds good :—

$$B\,C : b\,c = E\,C : E\,c, \text{ and } B\,C = b\,c \times \frac{E\,C}{E\,c}.$$

Again,

$$A\,C : ac = E\,C : E\,c, \text{ and } A\,C = a\,c \times \frac{E\,C}{E\,c}.$$

Hence,

The height $A\,B = B\,C + A\,C = (b\,c + a\,c) \times \frac{E\,C}{E\,c} = a\,b \times \frac{E\,C}{E\,c}.$

(2.) The horizontal line passes below the foot of the tree. Then C is situated below A and

$$A\,B = B\,C - A\,C = (b\,c - a\,c) \times \frac{E\,C}{E\,c} = a\,b \times \frac{E\,C}{E\,c}.$$

(3.) The horizontal line passes above the top of the tree. Then C is situated above B and

$$A\,B = A\,C - B\,C = (a\,c - b\,c) \times \frac{E\,C}{E\,c} = a\,b \times \frac{E\,C}{E\,c}.$$

In each of the above three cases, two observations are required, unless the foot of the tree happens to be at the same level as the eye of the observer ; the values of $a\,c$, $b\,c$, and $E\,c$ are read on the instrument, while $E\,C$ has to be measured.

The value of $a\,b$ can, however, be obtained by one observation in the following manner :—If two parallel objects are cut by two diverging rays, then the portions of the two parallel objects lying between the two rays are proportionate to the length of the rays. Let $E\,A$ be the length of a ray from the eye of the observer to the foot of the tree, $E\,a$ that from the eye to the plumb-line, $A\,B$ the height of the tree, and $a\,b$ the length of the plumb-line between the two rays going from the eye of the observer to the top and the foot of the tree ; then :—

$$E\,a : E\,A = a\,b : A\,B, \text{ and } A\,B = a\,b \times \frac{E\,A}{E\,a}.$$

The values of $a\,b$ and $E\,a$ are obtained from the instrument, and $E\,A$ must be measured. The instruments of this class are difficult to manage without a stand and, therefore, not to be recommended for ordinary work in the forest.

The measurement of the distance from the eye of the observer to the tree can be avoided by placing a staff, $M A$, of known length, L, alongside the foot of the tree. In this way, two further points M and m are given, as well as two similar triangles, $E M A$ and $E m a$. Thus we have (see Fig. 8) :—

$$E A : E a = A B : a b \text{ and } E A : E a = A M : a m,$$

hence,

$$A B : a b = A M ; \; a m, \text{ and } A B = H = \frac{a b}{a m} \times A M = \frac{a b}{a m} \times L.$$

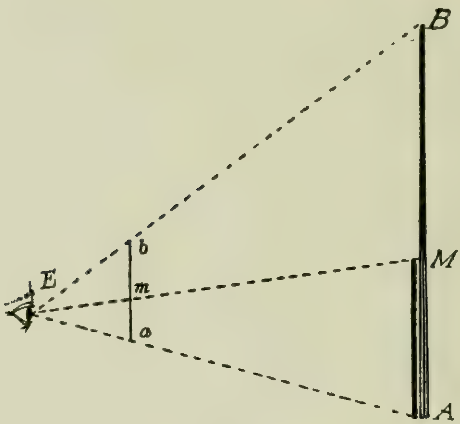


Fig. 8.

This method is very simple, but somewhat less accurate than that which includes the measurement of the distance of the observer from the tree, because $a m$ is very small and difficult to read accurately. The longer the staff L is, the more accurate will be the result.

Measurements made with hypsometers based on the geometrical principle, especially those used without a stand, are liable to yield inaccurate results owing to various causes, such as inaccurate reading due to the unsteadiness of the plumb-line in windy weather, inaccurate measurement of the base line, and slanting position of the tree. The most accurate results are obtained if the distance of the observer from the tree equals the height of the tree. The inaccuracy of measurement with the better hypsometers should not exceed 2 per cent. of the height of the tree.

b. Trigonometrical Height Measuring.

This is based upon the measurement of the angles of elevation and depression indicated by rays running from the eye of the observer to the top and foot of the tree. In the triangle, $E\,C\,B$ (Fig. 9), we have $B\,C = E\,C \times tan.\ u$, and in triangle $E\,C\,A$, $A\,C = E\,C \times tan.\ 1$; the height of the tree, $H = B\,C + A\,C = E\,C \times (tan.\ u + tan.\ 1)$. If the horizontal line of vision passes below the foot of the tree, the above formula becomes $H = E\,C \times$

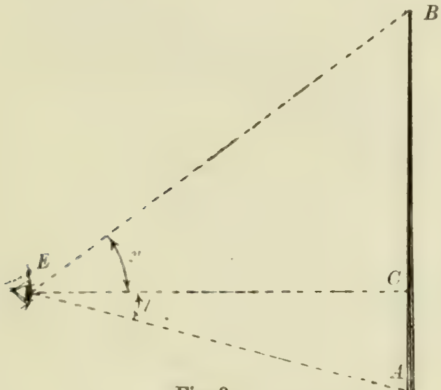


Fig. 9.

$(tan.\ u - tan.\ 1)$. If it passes above the top of the tree, $H = E\,C \times (tan.\ 1 - tan.\ u)$.

In each of these three cases, the measuring of the distance, $E\,C$, can be avoided by placing a staff of known length alongside the foot of the tree. In that case (Fig. 10, next page), we have :—

$$M\,C = E\,C \times tan.\ m, \text{ and } A\,C = E\,C \times tan.\ 1\,;$$

and
$$M\,A = E\,C \times (tan.\ m + tan.\ 1).$$

Hence
$$E\,C = \frac{M\,A}{tan.\ m + tan.\ 1}.$$

By introducing this value into the former equation, the height is :—

$$H = M\,A \times \frac{tan.\ u + tan.\ 1}{tan.\ m + tan.\ 1}.$$

All instruments which measure vertical angles are suited for trigonometrical height measuring. For practical purposes, it is desirable that the instrument should not require a stand; it is a

further advantage if, besides the angles, the corresponding tangents are marked on it.

c. Description of some of the more useful Hypsometers.

Weise's Hypsometer.—It consists of a tube, *T*, with an objective in the shape of a cross at one end, *O*, and an eyepiece, *E*, at the other. A scale is fastened longitudinally to the tube (called the height scale, *H*, Fig. 11), which is toothed on one side. It has the

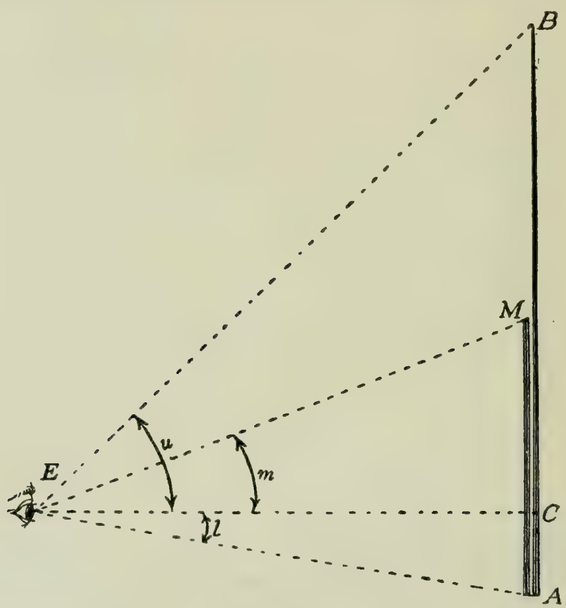


Fig. 10.

zero point some distance from the end, and it is graduated from it in both directions. A second scale, *D* (called the distance scale), is inserted at the zero point of the height scale and moves at right angles to it. From the upper or zero point of this scale depends a plumb-line *P*. When not in use, the distance scale and plumb-line are kept in the tube.

In using the instrument, a position is chosen from which both the top and foot of the tree can be seen; then, the horizontal distance from the point of observation to the tree is measured, and the distance scale drawn out until it indicates at the zero

point of the height scale the number of units in the distance; then the tube is raised and directed to the top of the tree, taking care that the up and down line of the objective keeps a vertical position. As soon as the horizontal line of the cross covers the

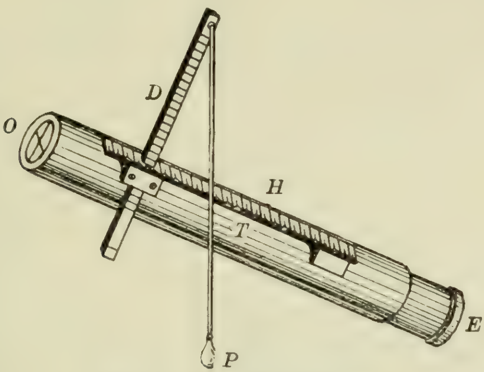


Fig. 11.—Weise's Hypsometer.

top of the tree, the tube is gently turned from left to right, whereby the plumb-line is caught by the toothed edge of the height scale. The number of units at the point where the plumb-

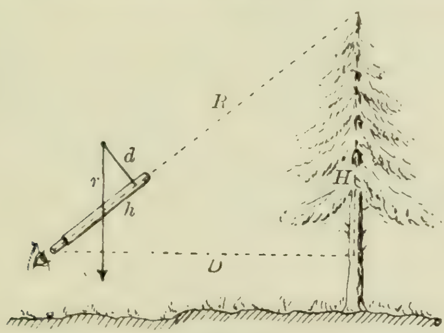


Fig. 12.

line was arrested give the height of the tree above the horizontal line in feet or yards, as the case may be. The number of units of measurement between the horizontal line and the foot of the tree is ascertained in the same way by directing the tube to the foot of the tree. The sum of the two readings gives the total height of the tree.

The theory of the instrument rests upon the similarity of the triangle with the sides $R\ H\ D$ and $r\ h\ d$ (see Fig. 12). The following equation holds good :—

$$d : h = D : H, \text{ and } H = D \times \frac{h}{d}.$$

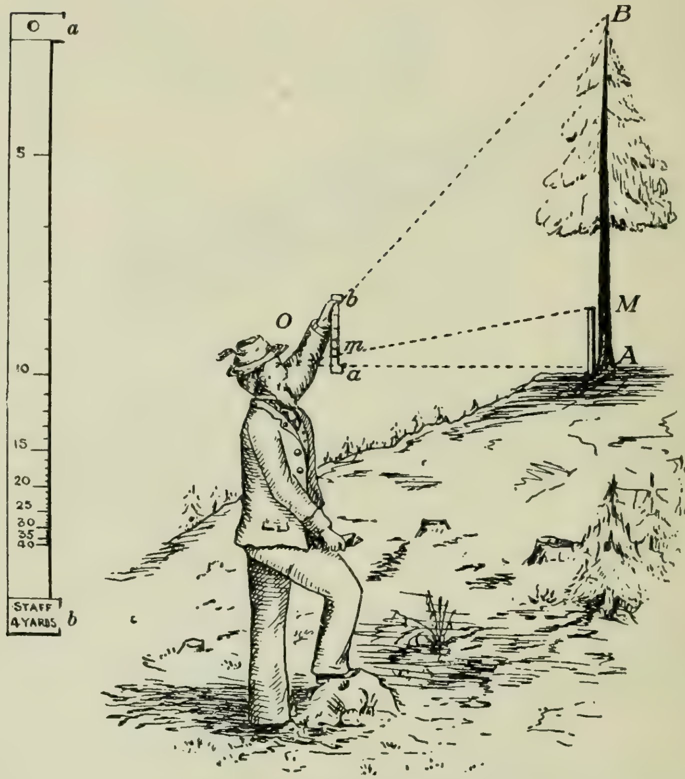


Fig. 13.—Christen's Hypsometer.

If, therefore, the units of the scales, which give h and d, are of the same size, and d is so fixed that its units are the same number as the units of the measured distance D, it follows that the above formula gives the height in feet or yards respectively, according to whether the distance, D, is given in the one or the other of these units.

Christen's Hypsometer.—This consists of a piece of metal with protruding upper and lower edges (see at a and b, Fig. 13). The

instrument is based upon the theory explained above, which avoids the measurement of a base-line. A staff of known length, L, say 4 yards, is placed alongside the foot of the tree. The instrument is then held in a vertical position at some distance from the observer's eye and moved forward and backward, until the top of the tree is seen along the upper edge, b, and the foot along the lower edge, a; then the point where a ray from the eye of the observer to the top of the staff, at M, hits the instrument, at m, gives the height of the tree. The instrument is constructed in the following way: Similar triangles are formed in which the following equation holds good :—

$$A\,B : a\,b = A\,M : a\,m, \text{ and } A\,B = \frac{a\,b}{a\,m} \times L\,; \text{ also } a\,m = \frac{a\,b}{A\,B} \times L.$$

If now $a\,b = 12$ inches, $L = 4$ yards, and successive values of $A\,B$, the height, are introduced, the corresponding values of $a\,m$ are obtained and marked on the instrument. Thus, the heights can be read off the instrument, as stated above. The marks on the instrument are cuts, as then the top of the staff is more easily seen.

The instrument has the disadvantage that the cuts are very close to each other for heights over 30 yards. This has lately been obviated to some extent by lengthening the instrument and making it with a hinge in the middle, so that it can be folded up when out of use. It is a very practical instrument, say, up to a height of about 100 feet, but it cannot be recommended for trees above that height.

Brandis' Hypsometer.—This is based upon the trigonometrical method of height measuring. It consists of a tube with an objective O at one end and an eye-piece, E, in the shape of a horizontal slit, at the other. Attached to the tube is a wheel which is weighted on one side (see at a, Fig. 14) and swinging between two pivots, so that it always maintains the same position when in use. Oscillations of the wheel can be arrested by a stop at S. That point of the wheel which corresponds with the horizontal line is marked as zero, and from this point the wheel is graduated up to 60 degrees up and down. A lens is fastened alongside the eye-piece to facilitate the reading of the angle when the tube is directed to any point. The wheel is placed in a firm metal case.

In using the instrument, a position is taken from which the top and foot of the tree can be seen, the angles to the top and foot are read, and the distance from the eye of the observer to the tree is measured. Then $H = E\,C\,(tan.\,u + tan.\,1)$ (see Fig. 9, on p. 19). For convenience of calculation, Brandis changed this formula as follows :—

$E\,C = E\,A \times cos.\,1$, and $H = E\,A \times cos.\,1 \times (tan.\,u + tan.\,1)$,

and $H = E\,A \times cos.\,1 \times \dfrac{sin.\,u \times cos.\,1 + sin.\,1 \times cos.\,u}{cos.\,u \times cos.\,1} =$

$$E\,A \times \frac{sin.\,(u + 1)}{cos.\,u}.$$

Brandis uses the last formula, which involves the measurement of

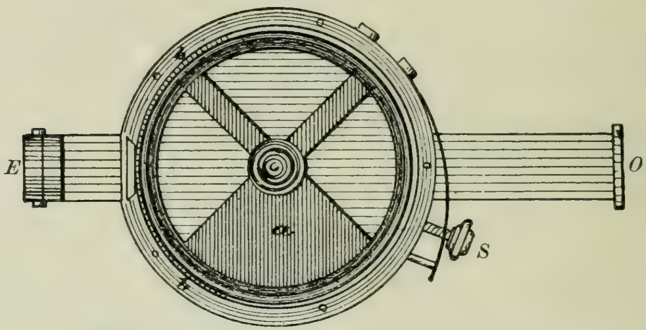


Fig. 14.—Brandis' Hypsometer and Clinometer.
(The front lid removed, so as to show the wheel.)

$E\,A$, the distance from the eye of the observer to the foot of the tree. A table accompanies the instrument, in which the heights corresponding to various distances and upper + lower angles are given. This table gives the upper angles at intervals of 2 degrees, and the lower angles at intervals of 5 degrees ; it is therefore necessary to place a staff with marked feet alongside the tree, so as to read on it the distance between the point where the lower ray hits the tree and its foot ; this has to be added to the measurement of the height.

Brandis' instrument is at the same time a clinometer, with which angles of slopes can be measured and roads laid out. It may, therefore, be considered the most useful of the instruments here described.

6. The Xylometer, used for the Direct Measurement of the Volume.

The method is based upon the fact that a body submerged in water displaces a volume equal to its own. The instrument consists of a graduated vessel (Fig. 16) to which a graduated scale is fixed. Before and after submersion, the level of the water is read on the scale, and the difference gives the volume of the submerged body. The method is used for the measurement of irregular pieces, such as rootwood and faggots. To obviate the necessity of submerging large quantities of wood, the whole is first weighed

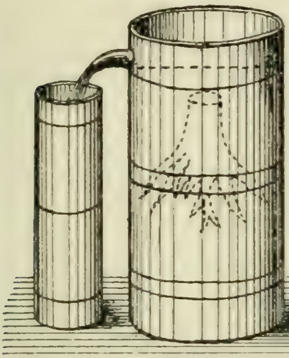


Fig. 15.

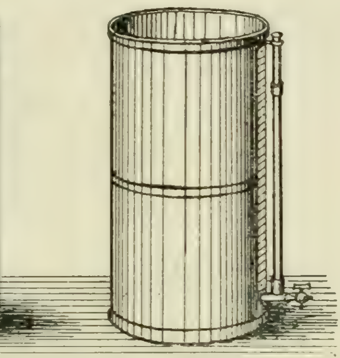


Fig. 16.

and only a portion submerged. Let the weight of the whole be W, that of the submerged part w, the volume of the former V and of the latter v, then $W : w = V : v$, and $V = v \times \frac{W}{w}$.

Instead of having a scale attached to the xylometer, the latter may be filled with water up to an opening, the wood submerged, and the outflowing water caught in a graduated vessel (Fig. 15).

In scientific investigations the xylometer is used in the determination of the specific gravity and the solid volume of amorphous pieces of wood by the hydrostatic method. Although these matters are rarely required in practical forestry, the following notes on them may here be recorded :—

7. Determination of the Specific Gravity of Wood.

The specific gravity of a piece of wood is the ratio which its weight bears to the weight of an equal volume of water ; in other

words, water is the standard of measurement and its gravity is placed at 1. A cubic foot of water at a temperature of 4° Celsius weighs 62·5 lbs., and the specific gravity of any wood is found by dividing its weight in pounds per cubic foot by 62·5; conversely, the weight in pounds per cubic foot of any wood is obtained by multiplying 62·5 by its specific gravity. Wood will sink or float according as its weight per cubic foot is more or less than 62·5, or its specific gravity more or less than 1.

Example.—A piece of wood weighs 58 lbs. per cubic foot; its specific gravity is $= \frac{58}{62{\cdot}5} = {\cdot}928$. Or, a piece of wood has a specific gravity of 1·124; its weight per cubic foot is $= 62{\cdot}5 \times 1{\cdot}124 = 70{\cdot}25$ lbs.

Methods of Determination.—(1.) A regular shaped piece of wood is found, by mensuration, to have a volume $= V$, and its weight $= W$ in pounds; then its specific gravity $= \frac{W}{V \times 62{\cdot}5}$ and its weight in pounds per cubic foot $= \frac{W}{V}$.

Example.—A rectangular piece of wood of the dimensions 12″ × 9″ × 8″ has a volume = ·5 cubic feet and weighs 30 lbs.

$$\text{Its specific gravity} = \frac{30}{62{\cdot}5 \times {\cdot}5} = {\cdot}96$$

$$\text{Weight per cubic foot} = \frac{30}{{\cdot}5} = 60 \text{ lbs.}$$

(2.) If the wood is of an irregular shape its specific gravity may be determined either by the xylometric or by the hydrostatic method.

(*a*) *Xylometric Method.*—The weight of the wood is found on a balance and the volume by submersion in a xylometer. The specific gravity or the weight in pounds per cubic foot is then calculated as described above for the regular shaped pieces.

(*b*) *Hydrostatic Method.*—Weight of the wood in the air, W; its weight while submerged in water, W'; then, as the loss of weight in water is equal to the weight of the same volume of water, specific gravity $= \frac{W}{W - W'}$.

Example.—A piece of wood, which sinks in water, weighs 10·875 lbs. in air and 1·1875 lbs. when suspended in water; its

$$\text{specific gravity} = \frac{10{\cdot}875}{10{\cdot}875 - 1{\cdot}1875} = 1{\cdot}123.$$

If the wood floats in water, a weight, or sinker, must be added; let S be the weight of the sinker under water. The specific gravity of the wood $= \dfrac{W}{W + S - W'}$.

Example.—Let W (in the air) be $= 3{\cdot}5$ lbs., S (in water) $= 6{\cdot}25$ lbs., and the combined weight of wood and sinker under water, $W' = 5{\cdot}875$ lbs. Then, specific gravity of the wood $= \dfrac{3{\cdot}5}{3{\cdot}5 + 6{\cdot}25 - 5{\cdot}875} = {\cdot}903$.

8. Determination of the Solid Volume by the Hydrostatic Method.

It has been shown above that if a piece of wood sinks in water its specific gravity is

$$= \frac{W}{V \times 62{\cdot}5} \text{ and also} = \frac{W}{W - W'};$$

hence $V \times 62{\cdot}5 = W - W'$ and $V = \dfrac{W - W'}{62{\cdot}5}$.

If the wood does float:—

$$\text{Specific gravity} = \frac{W}{V \times 62{\cdot}5} \text{ and also} = \frac{W}{W + S - W'};$$

hence $V \times 62{\cdot}5 = W + S - W'$, and $V = \dfrac{W + S - W'}{62{\cdot}5}$.

The volume of the sinker should be deducted from V.

Examples.—A sinking wood weighs in air $= 35{\cdot}25$ lbs.; in water $= 7{\cdot}5$ lbs.

$$\text{Volume} = \frac{35{\cdot}25 - 7{\cdot}5}{62{\cdot}5} = {\cdot}444 \text{ cubic feet.}$$

A piece of floating wood weighs in air $= 9{\cdot}0625$ lbs.; $S = 6{\cdot}25$ lbs. in water; wood $+ S$ in water $= 4{\cdot}1875$;

$$V = \frac{9{\cdot}0625 + 6{\cdot}25 - 4{\cdot}1875}{62{\cdot}5} = {\cdot}178 \text{ cubic feet.}$$

From this the volume of the sinker is to be deducted.

CHAPTER II.

MEASUREMENT OF THE VOLUME OF FELLED TREES.

The methods of measuring the various dimensions of felled trees have been explained in Chapter I. In this place the determination of the volume will be dealt with.

Each tree consists of a stem or trunk, branches and roots. These have peculiar shapes of their own which differ considerably; hence, they must be considered separately.

1. Volume of the Stem.

If the stem, or trunk, of a tree had a regular or distinct geometrical shape, its volume could be calculated direct by means of a formula corresponding to that particular shape. As a matter of fact, the stem shows different shapes in different parts of the tree. Again, the shapes of trees differ widely according to species, age and the conditions under which they have grown up, whether in the open or in a fully stocked wood. At the same time, trees of the same species and age, grown under the same conditions, generally show shapes which are nearly identical. Moreover, experience has shown that each part of the stem shows approximately a constant form. Thus, the uppermost part, *a* (Fig. 17), of an undivided stem has generally the shape of a cone, the lowest part, *c*, that of a neiloid (truncated semi-cubical paraboloid), while the greater part of the trunk, between the two extreme ends, has a shape between a cylinder and a cone, which differs somewhat from that of a paraboloid, but the difference is generally small. Hence,

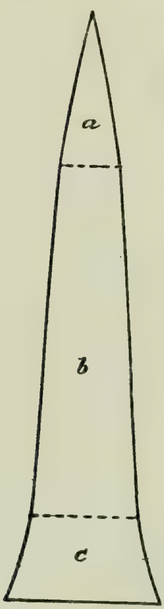


Fig. 17.

the calculation of the volume may be effected by the use of the following formula :—

If h = the height, or length,
S = the lower cross section,
s = the upper cross section, and
s_m = the middle cross section (Fig. 18),

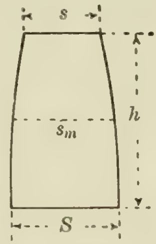


Fig. 18.

the volume, V, of each of the above-mentioned truncated solids is, according to (Simpson's) rule—

$$V = \frac{S + 4 \times s_m + s}{6} \times h.$$

This formula reduces—

$$\text{For the cylinder to } V = S \times h$$

$$\text{For the cone to } V = \frac{S \times h}{3}$$

$$\text{For the truncated paraboloid to } V = \frac{S + s}{2} \times h, \text{ or, } = s_m \times h.$$

The first of these two formulas is known as Smallian's formula, and the second as Huber's formula.

By means of these formulas it would be possible to calculate the volume of each part of the stem, provided its particular shape had first been ascertained. This, however, would be a tedious business, and it is necessary to search for a more simple procedure.

As by far the greater portion of the stem approaches in shape a truncated paraboloid, it has been found that, if the stem is divided into a number of pieces of moderate length, each can, without committing any appreciable error, be considered as a truncated paraboloid. Of the two formulas the latter ($V = h \times s_m$) is the more convenient, and experience has shown that it is even more accurate than the former.

According to this method, the volume of the whole stem is obtained by means of the following formula (see Fig. 19) :—

$$\text{Volume of stem} = s_1\, h_1 + s_2\, h_2 + s_3\, h_3 + \ldots,$$

where s_1, s_2, s_3 . . . are the areas of the cross sections taken in the middle of successive paraboloids, and h_1, h_2, h_3 . . . the

corresponding heights, or lengths. If the pieces are made of equal length, the above formula changes into the following :—

$$\text{Volume of stem} = (s_1 + s_2 + s_3 + \ldots)\, h.$$

This formula is used in all scientific investigations, and the degree of accuracy with which it works depends on the length of the pieces.

For the purposes of determining the yield of woods and for the sale of logs, the formula is further simplified by considering each log as one paraboloid ; in other words, the volume is calculated

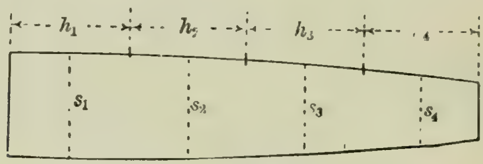


Fig. 19.

from the middle section of the log multiplied by its length, according to the formula—

$$V = S_m \times H,$$

where S_m represents the area of the circle, or sectional area, in the middle, and H the total length of the log. Experience has shown this formula to give sufficiently accurate results for all practical purposes.

The area of the cross-section is obtained, either by measuring the girth, or the diameter. If g = girth, d = diameter, and r the radius, the section is—

$$S = \frac{g^2}{4\pi} = \cdot 0796 \times g^2,$$

or

$$S = \frac{\pi\, d^2}{4} = \cdot 785 \times d^2 = r^2 \times \pi,$$

and

$$V = \cdot 0796 \times g^2 \times H = \cdot 785 \times d^2 \times H = r^2 \times \pi \times H.$$

In practical work, the sectional areas are taken from specially prepared tables ; there are also tables which give directly the volume of logs according to their mean girth and length, or their mean diameter and length. (See Appendix I.)

All these calculations are made on the assumption that the section represents a circle. This is, however, rarely the case.

As a rule, the degree of divergence from the circular shape depends on :—

(1.) The part of the stem ; generally the lowest and uppermost parts differ most.

(2.) The age of the tree ; young trees are more regularly shaped than old ones.

(3.) The species.

(4.) The conditions under which the tree has grown up ; in fully stocked woods the shape is more regular than in the case of trees grown in the open ; exposure to strong winds, slanting position, and the nature of the soil also affect the shape.

Generally, the sections of trees approach the shape of an irregular ellipse, the greater axis of which lies, in the same locality, as a rule in a constant direction. Where trees are much exposed to wind, the greater axis lies generally in the direction of the prevailing wind : in Western Europe, therefore, from west to east or from south-west to north-east.

The inaccuracy caused by measuring the girth, and calculating therefrom the sectional area, has been found to amount, on an average, to about 7 per cent. ; where only one diameter is measured, the error may be the same or even more ; where two diameters at right angles are measured and the mean taken, the error generally does not exceed 2 per cent. of the true amount. It follows that the latter is more accurate than the method of basing the calculation of the volume on the girth.

In Britain and in India the sectional area in the middle is calculated by the method of the quarter-girth, that is to say, by the formula—

$$S = \left(\frac{g}{4}\right)^2 = \cdot 0625 \times g^2.$$

In comparing this with the real sectional area $= \cdot 0796 \times g^2$, it is found that the quarter-girth method gives only 78·5 per cent. of the true basal area and volume, omitting 21·5 per cent. The method is based upon the assumption that this amount represents the waste incurred in squaring the timber. Quantities calculated by the exact method can be converted into the quantities corresponding to the other by deducting 21·5 per cent. of the volume. If the bark has been omitted in the measurements in

both cases, no further correction is required. In measurements according to the quarter-girth, it is usual to deduct for the bark one inch out of every twelve of the quarter-girth, before the latter is squared. Hence, the deduction on account of bark comes to $12 \times 12 - 11 \times 11 = 144 - 121 = 23$ square inches out of every 144. In other words, a reduction of 16 per cent. is made on account of bark. This may be too much in some cases and too little in others. It is a much better plan, in the case of felled logs, to remove a ring of bark, and to measure the girth or diameter over the wood only.

2. Volume of Branch and Root Wood.

In some cases, pieces of branch and root wood are of a sufficiently regular shape to measure and calculate their volume in the manner given above. As a general rule, however, such wood requires a different treatment. Its volume is ascertained by shaping it according to custom and stacking it in a space of regular geometrical form, say, 100 cubic feet. Such a space would contain a certain amount of wood and of air. In order to obtain the proportion of each, the volume of some stacks of the different classes of wood, such as split wood, round billets, branch wood, faggots, or root wood, is carefully ascertained. This can be done by measuring each piece separately, an operation of considerable difficulty, and one which takes much time. A more expeditious way is to submerge the material in a xylometer (see page 25) and ascertain the volume by measuring the quantity of the displaced water. From the data thus obtained, average coefficients are calculated and used on subsequent occasions.

It is evident that different descriptions of wood give different coefficients. The solid contents of stacked wood depend on many things, amongst which may be mentioned :—

(1.) Shape and nature of the pieces : thick, smooth and straight pieces give more solid contents than thin, bent, uneven pieces.

(2.) Length of pieces : short pieces pack better than long ones ; hence, they give a higher percentage of solid contents.

(3.) Method of stacking : careful stacking causes the percentage of solid wood to be considerably increased.

Under these circumstances, the coefficients differ in accordance

with local conditions. By way of illustration, the following may be given :—

Split firewood	= ·7
Round firewood billets under 5″ diameter .	= ·6
Root and stump wood	= ·5
Faggot wood stacked (not bound) . .	= ·2

That is to say, 100 cubic feet of stacked split firewood contain 70 cubic feet of solid wood and 30 cubic feet of air, etc.

3. Volume of the Bark.

In many cases it is desirable to ascertain the volume of the bark, especially when it is sold separately, as in the case of tanning bark. This can be done stereometrically or xylometrically. In the former case, the pieces of wood are measured before and after barking, the difference giving the volume of the bark. If a xylometer is used, the bark can be measured separately, or the pieces of wood are immersed before and after barking.

According to species, age, and locality, the bark comprises from 4 to 20 per cent. of the total volume. Schwappach found on a number of trees the following percentage of bark :—

Oak . .	= 15—20	Alder . .	= 16—19
Ash . .	= 12—14	Lime . .	= 16—19
Elm . .	= 9—11	Aspen . .	= 9—13
Birch . .	= 13—17	Scots Pine .	= 10—16

The Forestry Commissioners have published in their Bulletin No. 3 figures obtained from numerous measurements made in regular woods, which gave the following results :—

Percentage of Bark.

Quality Class according to Height at 50 years of Age.	Larch. Per cent.	Spruce. Per cent.	Scots Pine, Scotland. Per cent.	Scots Pine, England. Per cent.
80 feet . .	18	10	..	..
70 ,, . .	19·5	10	..	..
60 ,, . .	21	10	13·5	12·5
50 ,, . .	22	11	15	13
40 ,, . .	22·3	12	16·5	13·5
30 ,, . .	..	..	17	16

Tanning bark is usually sold by weight; other bark is sold according to measurement, like firewood.

In Britain, figures are sometimes locally obtained which indicate the proportion between the quantity of timber and that of tanning bark. Such figures vary according to local conditions and custom.

CHAPTER III.

MEASUREMENT OF STANDING TREES.

1. Ocular Estimate.

Originally, the volume of standing trees was estimated. Such an estimate takes into consideration the special shape or form of each tree, and fixes the volume accordingly. The accuracy of purely ocular estimates depends entirely on the person who makes them. To be only approximately correct, the estimator requires great practice and occasional opportunities to compare his estimates with actual measurements after the trees have been felled. Even then, the results are subject to considerable errors, unless the estimator practises his art constantly. Mistakes of 25 per cent. are of common occurrence, and they may reach up to 100 per cent. in the case of an inexperienced estimator.

The uncertainty of purely ocular estimates led to the measurement of diameter (or girth) and height; this done, the basal area near the ground can be calculated, multiplied by the height, and an estimate made of the actual volume of the tree. It stands to reason that such an estimate is less dependent on the individuality of the estimator than that mentioned above, since he has only to estimate the proportion which exists between the actual volume and that of an imaginary body constructed out of the height and the sectional area near the base, a matter which he must decide according to the peculiar shape of the tree. By degrees, it was considered desirable to collect data regarding the form of various trees which might be utilized in subsequent estimates, and thus foresters arrived at the method next to be described.

2. Measurement of Volume by means of Form Factors.

a. Definition and Classification of Form Factors.

By "form factor" is understood the proportion which exists between the volume of a tree and that of a regularly shaped body of the same base and height as the tree. The form factor means, therefore, a coefficient with which the volume of the regularly shaped (geometrical) body must be multiplied in order to obtain the volume of the tree.

Any regularly shaped body, the volume of which can easily be calculated by means of a mathematical formula, is suited for the purpose. In practice, only the cone and cylinder have been employed, and at the present time only the latter is used. Let s be the area of the basal section of the tree, h its height, f the form factor, and v the volume, then—

$$\text{Volume of cylinder} = s \times h,$$
$$\text{Volume of tree} = v = s \times h \times f,$$

and

$$\text{Form factor} = f = \frac{v}{s \times h}.$$

Various kinds of form factors are used in forestry, of which the following may be mentioned :—

(1.) Stem form factors, which refer only to the volume of the stem above ground.

(2.) Tree form factors, which refer to stem and branches, omitting root wood.

(3.) Timber form factors, which refer only to the parts of the tree classed as timber, whether they are taken from the stem or branches, omitting all other material.

The volume of the stem of a tree by itself is always smaller than that of the corresponding cylinder ; hence, the form factor for the stem only is always smaller than 1. If the volume of the branches is added, the form factor is sometimes greater than 1, especially during the early youth of the tree.

Form factors for branch wood, faggots, or root wood only are, as a rule, not used ; their volume is ascertained by utilizing the results of actual fellings and determining their proportion to the volume of timber.

As it would be highly inconvenient to measure the diameter, or girth, of the tree close to the surface of the ground where it is usually cut, it has been agreed to take the measurement at a convenient height. According to whether that point is fixed or variable, the following kinds of form factors may be distinguished :—

(1.) *Absolute Form Factors.*—The diameter (or girth) is measured at any convenient height above the ground, and the form factors refer only to the part *a* of the tree above that point (Fig. 20), while the volume of the piece *b* below it is ascertained by separate measurement and added to the part above it. This is evidently troublesome and takes extra time.

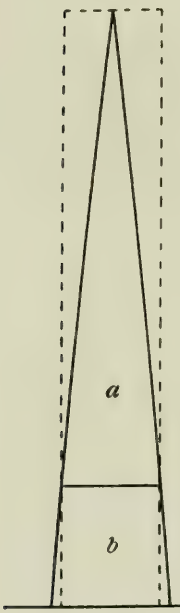


Fig. 20.

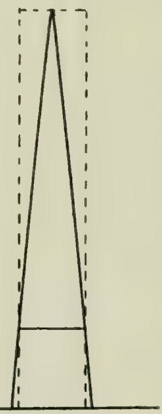


Fig. 21.

(2.) *True or Normal Form Factors.*—The diameter (or girth) is measured at a constant proportion of the height of the tree, say, $\frac{1}{10}$th, $\frac{1}{20}$th, etc. (Figs. 20 and 21). In this case, the height of the ideal cylinder is equal to the height of the tree. Such form factors, it was believed, would have the advantage that all trees of the same shape would have the same form factor, since they have been measured at a height which bears in all cases the same proportion to the total height. There are, however, various drawbacks to the employment of these form factors. In the first place, the height of the tree must be determined before the point of measurement can be fixed ; secondly, the latter may be very inconvenient in the case of very tall, as well as very short trees ; thirdly, it has been found from actual measurements that the factors thus obtained are by no means as regular as had been supposed ; that is to say,

trees of different heights show by no means the same form factor if measured at a constant proportion of the height.

(3.) *Form Factors based on Measurements made at Height of Chest, called Artificial Form Factors.*—The diameter (or girth) is measured at the most convenient height from the ground—namely, at chest height of an ordinary man. (In Germany and France now generally fixed at 1·3 meters = about 4 feet 3 inches.) The height of the ideal cylinder is equal to the height of the tree. Owing to the measurements being taken at an absolutely constant height from the foot of the tree, the form factors of two trees which show the same shape but differ in height are not the same. It follows that, in using such form factors for calculating the volume of trees, the height of the latter must be taken into consideration. Nevertheless, in practice, these are the only form factors now used.

b. Determination of Form Factors.

At first, form factors were estimated, taking into consideration all points which affect them, such as species of tree, height, age, free or crowded position, etc. Such an operation requires much skill and practice, and it comes practically to the same thing as estimating the volume direct. To eliminate such uncertainty, tables have been prepared which give the form factors for different species, heights, and ages, such tables being based upon the results obtained by the measurement of numerous felled trees. Of late years, it has been recognised that, for ordinary purposes, the variations due to age can be omitted, except where great accuracy is required, as in scientific investigations.

The following table shows the form factors, taken from Continental yield tables (see next page):—

In using these tables, it must not be forgotten that they give the averages of numerous measurements; hence, they do not give reliable results in calculating the volume of a single tree. Their application should be restricted to the calculation of the volume of a number of trees; in other words, of whole woods, where the differences between the several trees are likely to compensate each other:—

Table of Form Factors, taken from Continental Tables.

Height of Tree or Wood. Feet.	Oak.	Beech.	Alder.	Birch.	Scots Pine.	Spruce.	Silver Fir.	Larch.	Height of Tree or Wood. Feet.
	Form Factors for Timber in the round and Faggots.								
20	·70	·76	·56	..	·86	1·02	1·10	·77	20
30	·63	·69	·51	·23	·72	·89	·82	·66	30
40	·60	·65	·52	·34	·64	·78	·69	·62	40
50	·59	·61	·52	·45	·58	·71	·64	·58	50
60	·59	·60	·52	·53	·55	·66	·61	·55	60
70	·58	·59	·52	·56	·53	·62	·60	·52	70
80	·58	·58	·51	·56	·52	·59	·59	·50	80
90	·58	·58	..	..	·51	·57	·58	·48	90
100	·58	·59	..	..	·50	·55	·57	·47	100
110	·58	·60	..	..	·50	·53	·56	·46	110
120	·58	·61	..	..	·49	·52	·55	·45	120
130	..	..	..	..	..	·52	·55	·44	130
140	..	..	..	..	..	·52	·55	·43	140
150	..	..	..	..	..	·51	..	..	150
	Form Factors for Timber in the round down to 3 inches Diameter.								
20	·31	·19	·20	..	·32	·36	·40	·32	20
30	·37	·33	·30	·12	·38	·48	·45	·39	30
40	·45	·41	·40	·26	·44	·52	·48	·44	40
50	·49	·45	·45	·37	·46	·53	·49	·46	50
60	·51	·47	·49	·43	·47	·53	·50	·45	60
70	·52	·48	·49	·45	·47	·54	·50	·44	70
80	·52	·49	·48	·45	·47	·52	·51	·43	80
90	·52	·49	·47	..	·47	·51	·52	·43	90
100	·53	·50	·46	..	·46	·50	·51	·43	100
110	·53	·52	..	..	·46	·49	·51	·42	110
120	·53	·54	..	..	·46	·49	·50	·42	120
130	..	..	..	..	..	·48	·50	·41	130
140	..	..	..	..	..	·48	·50	·40	140
150	..	..	..	..	..	·47	..	..	150
	Form Factors for Timber according to Quarter-Girth Measurement.								
20	·23	·14	·15	..	·24	·27	·30	·24	20
30	·29	·25	·23	·09	·29	·36	·34	·29	30
40	·34	·31	·30	·20	·33	·39	·36	·33	40
50	·37	·34	·34	·28	·34	·40	·37	·35	50
60	·38	·35	·37	·32	·35	40	38	·34	60
70	·39	·36	·37	·34	·35	·40	·38	·33	70
80	·39	·37	·36	·34	·35	·39	·38	·32	80
90	·39	·37	·35	..	·35	·38	·39	·32	90
100	·40	·38	·34	..	·35	·38	·38	·32	100
110	·40	·39	..	..	·34	·37	·38	·31	110
120	·40	·40	..	..	·34	·37	·38	·31	120
130	..	..	..	..	..	·36	·38	·31	130
140	..	..	..	..	..	·36	·38	·30	140
150	..	..	..	..	..	·35	..	..	150

Form Factors for larch, spruce, and Scots pine so far obtained in Britain will be found in Appendix IV.

3. Measurement of Volume by means of Volume Tables.

If, instead of giving the form factors only, they are multiplied by the corresponding heights and basal areas, the volumes of the trees are obtained, which can be arranged into so-called "volume tables." The latter may be defined as tables which give the volume of single trees arranged according to species, diameter, height and in some cases also according to age.

These tables rest upon the assumption that trees of the same species, which have reached an equal height and diameter (basal area) in about the same time, show also an equal volume. As regards the age of the trees, experience has shown that it affects the volume to some extent, even for the same height and basal area, because with advancing age the stems become somewhat more full-bodied or less tapering; or the tapering commences at a greater height than in younger trees. Hence, volume tables are sometimes divided into two parts—say, for trees below half the rotation in age, and secondly for trees older than about half the rotation.

In order to use such tables, it is necessary to ascertain the diameter at chest-height, the total height and the approximate age of the tree, when the volume corresponding to these data can be obtained from the tables. It must, however, not be forgotten that the tables give only averages, and, consequently, only true results if used for determining the volume of a number of trees, or of whole woods.

Tables of this kind have been prepared in Germany and France for many years past; of late also by the Forestry Commission for larch and Scots pine. The numerous measurements made by the German Forest Statistical Association, during more than 50 years, have yielded a rich crop of data which have been arranged in tables according to species and dimensions. They are, no doubt, of great use, but they cover many pages, and it takes time to look up the particular dimensions. In the author's opinion, the method of taking the volume of the cylinder (equal to the height multiplied by the basal area) from the table in Appendix I., and multiplying it by the form factor, works quicker and suffices for all practical purposes.

Example.—An oak has a height of 80 feet, and a diameter of 24 inches at 4 feet 3 inches from the ground. The table in Appendix I. gives—

Volume of cylinder . . . = 251·3
The form factor for timber (page 38) = ·52
Volume of tree in the round . . = 251·3 × ·52 = 130·7.

Or, according to quarter-girth measurement,

Volume = 251·3 × ·38 = 98 cubic feet.

Extracts from the British tables are appended :—

British Volume Tables for Larch and Scots Pine.

Girth at 4 ft. 3 ins.	Total Height in Feet.							Girth at 4 ft. 3 ins.
	30—40	40—50	50—60	60—70	70—80	80—90	90—100	
Inches.	Volume per Tree (Cubic Feet under Bark).							Inches.
	LARCH.							
8	·08	..	..	..	..	..	..	8
12	·64	·66	·74	..	..	..	..	12
16	1·40	1·58	1·80	2·10	..	..	..	16
20	2·40	2·78	3·25	3·7	4·2	..	..	20
24	3·66	4·20	4·90	5·8	6·6	7·6	..	24
28	..	5·8	6·8	8·2	9·6	10·8	12·2	28
32	..	7·7	9·1	11·0	13·0	14·5	16·0	32
36	..	10·0	11·8	14·1	16·5	18·6	20·4	36
40	..	..	15·1	17·8	20·5	23·0	25·2	40
44	..	..	..	22·0	25·1	28·1	30·8	44
48	..	..	..	26·2	30·0	33·5	36·8	48
52	..	..	..	..	35·2	39·2	44·0	52
56	..	..	..	..	..	45·6	52·4	56
60	..	..	..	..	..	53·3	63·0	60
	SCOTS PINE.							
12	·64	..	..	..	..	..	..	12
16	1·29	1·85	..	..	..	..	..	16
20	2·1	2·88	..	..	..	..	..	20
24	3·2	4·14	5·3	6·5	..	..	..	24
28	4·5	5·48	7·1	8·6	..	..	..	28
32	..	7·0	9·2	11·1	13·0	..	..	32
36	..	8·8	11·5	13·9	16·3	..	..	36
40	..	..	13·9	16·8	19·8	..	..	40
44	..	..	16·4	19·8	23·6	28·0	..	44
48	..	..	19·0	23·0	27·4	32·0	..	48
52	..	..	21·8	26·3	31·3	36·4	..	52
56	..	..	24·9	29·8	35·6	41·2	..	56
60	..	..	..	33·5	40·2	46·4	..	60
64	..	..	..	37·8	45·3	52·8	..	64
68	..	..	..	..	51·2	61·0	..	68

4. Measurement of Standing Trees by Sections.

Analogous to the measurement of felled trees by sections, the volume of standing trees can be ascertained by determining the diameter (or girth) at various heights from the ground. For this purpose, a man must be sent up the tree, which is a cumbrous procedure, or the several diameters must be determined indirectly. The latter, as has been explained in Chapter I. (page 13), is subject to great inaccuracies.

Where the diameter at half height is wanted, it is often estimated from the diameter at height of chest. The method is a rough one, but much used in Britain, France, and Belgium. As far as the author is aware, no uniform method of estimating the girth or diameter at half height from the girth or diameter at, say, height of chest has been recognised in Britain. Consequently, the actual estimate depends on the individuality of the estimator. No wonder, then, that different estimators obtain different results. The calculation of the volume by means of form factors, which represent the average of numerous measurements of trees lying on the ground, leaves no latitude to the estimator. He measures the diameter of the tree at height of chest and the height; he takes the basal area and form factor out of a little table which he carries in his pocket and obtains the volume by a simple multiplication.

Example.—An oak tree, grown in a fairly stocked wood, has a diameter of 12 inches at height of chest and a total height of 70 feet. On reference to the table in Appendix I., it is found that the basal area, corresponding to a diameter of 12 inches, is $s = \cdot 7854$, and on reference to page 38 the form factor for a height of 70 feet will be found to amount to ·52 for timber in the round, or ·39 for quarter-girth measurement. Hence, the volume $V = \cdot 7854 \times 70 \times \cdot 52 = 28\cdot 5$ cubic feet in the round, or $V = \cdot 7854 \times 70 \times \cdot 39 = 21\cdot 4$ cubic feet quarter-girth measurement. The product of $\cdot 7854 \times 70$ can be obtained from the table in Appendix I. without multiplication.

On the other hand, according to British custom, the estimator has to do three things: (1.) to measure the girth at height of chest, say, = 38 inches; (2.) the length of serviceable timber, say 50 feet; and (3.) to estimate the girth at 25 feet from the ground. Supposing he estimates a decrease of 20 per cent., then the girth at 25 feet comes to about 30 inches, and the volume, according to the quarter-girth measurement, amounts to—

$$V = \frac{(7\cdot 5)^2 \times 50}{144} = 19\cdot 5 \text{ cubic feet.}$$

If he estimates the decrease of the girth at 15 per cent., the girth at 25 feet from the ground would be 32 inches, and

$$V = \frac{(8)^2 \times 50}{144} = 22{\cdot}2 \text{ cubic feet.}$$

If he estimates the decrease at 25 per cent., the girth at 25 feet comes to about 28 inches, and

$$V = \frac{(7)^2 \times 50}{144} = 17{\cdot}0.$$

In fact, the volume thus estimated would range from 17 to 22·2 cubic feet, and the only chance of obtaining the exact amount depends on the skill of the estimator, thus introducing a factor of considerable uncertainty.

The most urgent need for calculating the volume of trees grown in Britain in fairly well-stocked woods is the collection of data from which form factors and volume tables can be calculated, whether for determining the volume in the round or according to quarter-girth measurement. The Forestry Commission has made a beginning by publishing volume tables for larch and Scots pine. Similar tables for other species will, no doubt, follow. The method is, however, not applicable in the case of hedgerow trees, or others grown under similar conditions. In the latter case, each tree must be measured, or estimated, separately.

CHAPTER IV.

DETERMINATION OF THE VOLUME OF WHOLE WOODS.

This chapter may be divided into three sections according to whether the measurements extend over the whole wood, or only over a selected portion of it, or whether the volume is estimated.

SECTION I.—MEASUREMENTS EXTENDING OVER THE WHOLE WOOD.

The method demands a uniform treatment of the whole wood, but a distinction may be drawn between the measurement of all trees and that of selected trees called sample, or type, trees.

A. Determination of the Volume by the Measurement of all Trees.

Each tree is measured separately and its volume ascertained in one of the ways described in Chapter III. By adding up the volumes of the several trees, that of the whole wood is obtained.

As the method takes much time, it is, in practice, only employed when the total number of trees is small, or when the wood is of an irregular description. In all other cases, the following system is chosen, as it works more rapidly.

B. Determination of Volume by means of Sample, or Type, Trees.

The volume of a wood consists of the sum of the volumes of the individual trees. The volume of each tree is calculated according to the formula—

$$v = s \times h \times f,$$

where s represents the basal area at a certain height, h the total height, and f the form factor of the tree. In all cases where s, h and f differ from tree to tree, nothing remains but

to ascertain them separately for each tree as indicated under A. In the case of regularly grown woods, however, there are always a number of trees which show, at any rate approximately, the same basal area, height and form factor, so that they can be thrown together and dealt with in a uniform manner; in other words, all trees of a wood which show the same base, height and form factor are joined into one class; the volume of one tree (or of a few trees) is ascertained, and the volume of the whole class obtained by multiplying the former by the number of trees in the class. If every class is dealt with in the same way, the volume of the whole wood is obtained by adding together the volumes of the several classes.

So far, however, little or no advantage is gained, because it would be necessary to ascertain the base, height and form factor of each tree in order to put it into its proper class, and when this has been done, the volume of each tree may just as well be calculated separately. Moreover, in crowded woods the height is not always easy to measure, and the form factor could only be estimated, unless it is taken from a table. Only the basal area is easily ascertainable by measuring either the diameter or the girth.

Here, experience had to be called in, which fortunately showed that, in regularly grown, well-stocked woods, the height and form factor are approximately functions of the diameter of the tree; in other words, trees of the same diameter or girth have approximately the same height and form factor. At any rate, this is found to hold good to a sufficient extent, so as to justify a classification according to diameter, or girth, classes only.

In open woods, however, the height and form factor vary within such wide limits that, besides diameter classes, at any rate height classes also must be formed. In the case of selection forests and irregularly stocked woods generally, the volume of each tree must be separately ascertained.

1. Description of the General Diameter Class Method.

a. Formation of Diameter Classes.

The number of classes depends on the difference between the largest and smallest trees of a wood and the desired degree of

accuracy. As a rule, all classes are given the same extent, that is to say, either 1 inch, 2 inches, 3 inches, etc., or part of an inch. For the purpose of forest working plans in Europe, each class comprises 1 or 2 inches : in India frequently, as yet, 6 inches.

The calliper, used in measuring the diameters, should have a rounded-off scale, as described in Chapter I.—that is to say, in the case of inch classes, the first should comprise the space from $\frac{1}{2}$ to $1\frac{1}{2}$ inch ; the second that from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches, etc. For scientific investigations the classes may be further reduced to a part of an inch.

b. Height and Manner of Measurement.

All trees must be measured at the same height, the latter being so chosen that the place of measurement falls above the irregular swelling frequently observed near the foot of the tree ; at the same time, the height should not be so great that it becomes difficult for an ordinary-sized man to measure accurately. Whenever practicable, the height should be the height of chest of an average man, say, equal to 4 feet 3 inches.

In executing the measurement, all the precautions indicated in Chapter I. must be duly taken, so as to obtain as accurate results as possible. More especially, any irregularity in the shape of the sections must be duly considered. Where the section differs systematically from that of a circle, either two diameters at right angles must be measured, or the direction of measurement changed from time to time. For instance, after a certain number of stems have been measured with the face of the measurer to the east, an equal number must then be measured with the face of the measurer towards the north or south. Or the change can be made at alternate trees. In this manner, average diameters are obtained.

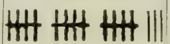
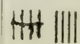
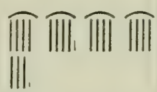
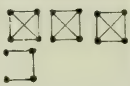
c. The Booking of the Measurements.

In measuring the diameter, the gaugers call out each measurement and in mixed woods also the species ; the book-keeper enters each announcement, repeating it at the time, so as to prevent mistakes.

A book-keeper may work with one or two gaugers, the party

taking a narrow strip of wood at the time ; each tree is marked as soon as measured, preferably with chalk.

The booking can be done in a variety of ways, as the following samples will show :—

Diameter in Inches, measured at 4′ 3″ from the Ground.	Species.			Number of Trees.			
	Beech.	Oak.	Ash.	Beech.	Oak.	Ash.	Total.
8				18	9	3	30
9				23	13	8	44
10				37	13	9	59
11	••••• ••••• ••••• ••••• ••••• ••	•••••••••• ••••	••••• ••	27	14	7	48
			Grand Total	105	49	27	181

The first two methods of booking are least liable to errors.

d. Selection and Number of Sample Trees.

As the volume of the whole class is to be calculated from that of the sample tree, it is necessary to select for the latter a tree which represents the average of the class : in other words, the sample tree should have the mean height, as near as possible a circular section, a fairly straight and not a forked stem, and an average extent of crown. Even with the greatest care, it is not always possible to avoid errors in the selection ; hence, it is generally advisable to take several sample trees for each class. The actual number of sample trees depends on the desired degree of accuracy and the total number of trees in the class. At the same time, the felling of many sample trees is undesirable ; hence, their number should be kept within reasonable limits.

A further requirement is that the sample tree should show a basal area which corresponds to the mean section of the class. Such a tree is not always found, so that it is necessary to take a tree as near as possible of the true section, and to modify the volume in proportion to the basal areas of the true and approximate sample trees. Let $v =$ volume of true sample tree, v' that of the approximate sample tree, s and s' the corresponding basal areas, then v is found by the formula—

$$v : v' = s : s'$$

and

$$v := v' \times \frac{s}{s'}.$$

e. Determination of the Volume of Sample Trees.

The volume of the sample trees is determined, either by felling and measuring them on the ground, or by means of form factors or volume tables.

If the tree is felled, the stem and all straight pieces of branches, in fact all regularly shaped parts, are divided into pieces of moderate length, from 3 to 10 feet, according to the desired degree of accuracy, and the volume of each section is ascertained separately by the formula (see page 29) :—

$$v = s_m \times h.$$

The volume of all irregular pieces, including root and branch wood, is ascertained, either by the xylometric method, or by proportionate figures, or by measuring their volume stacked, and multiplying it by reducing factors, if such are available.

The xylometric method has been explained in Chapter I.

Proportionate figures are obtained from actual fellings. If it has been found that in the felling of a wood every 100 cubic feet of timber are accompanied by, say, 20 cubic feet of firewood, that proportion can be applied to other woods of a similar description.

The determination of the volume of sample trees by means of form factors or volume tables can be highly recommended, whenever suitable tables are available, because they give averages, and that is just what is wanted in this case. Experience has shown

that form factors and volume tables are applicable for a considerable distance outside the locality for which they have been prepared.

f. Calculation of the Volumes of the Classes and of the Whole Wood.

Here several cases may occur :

(1.) One sample tree has been measured in each class, the dimensions of which are exactly the average of the class. In that case, the volume of the class is obtained by multiplying the volume of the sample tree by the number of trees in the class. If—

V = volume of whole wood,

$V_1, V_2, V_3 \ldots$ = volumes of classes 1, 2, 3 . . .

$v_1, v_2, v_3 \ldots$ = volumes of mean sample trees of successive classes.

$n_1, n_2, n_3 \ldots$ = numbers of trees in successive classes,

then—

$$V = V_1 \times V_2 + V_3 + \ldots = v_1 \times n_1 + v_2 \times n_2 + v_3 \times n_3 + \ldots$$

(2.) The sample trees in the several classes differ in basal area from the mean basal areas.

If the volumes of the approximate sample trees are v_1', v_2', v_3' . . . and the corresponding basal areas $= s_1', s_2', s_3', \ldots$ then

$$V_1 = \frac{v_1' \times s_1}{s_1'} \times n_1 ; \; V_2 = \frac{v_2' \times s_2}{s_2'} \times n_2 ; \; V_3 = \frac{v_3' \times s_3}{s_3'} \times n_3 \ldots$$

As

$s_1 \times n_1 = S_1$ = total basal area of the first class,

$s_2 \times n_2 = S_2$ = total basal area of the second class, etc.,

the volume of the wood is :—

$$\mathbf{V} = \frac{\mathbf{v_1' \times S_1}}{\mathbf{s_1'}} + \frac{\mathbf{v_2' \times S_2}}{\mathbf{s_2'}} + \frac{\mathbf{v_3' \times S_3}}{\mathbf{s_3'}} + \ldots$$

(3.) Several sample trees are measured in each class. In that case—

$$V = \frac{(v_1' + v_1'' + v_1''' + \ldots) \times S_1}{s_1' + s_1'' + s_1''' + \ldots} + \frac{(v_2' + v_2'' + v_2''' + \ldots) \times S_2}{s_2' + s_2'' + s_2''' + \ldots} + \ldots$$

g. Clubbing together several Classes, leading to the Method of the Arithmetical Mean Sample Tree.

In order to shorten the method described above and to reduce the number of sample trees to be felled, several, or all, classes may be clubbed together into a group.

Let

$n_1, n_2, n_3 \ldots$ be the numbers of trees in the several classes
$s_1, s_2, s_3 \ldots$,, basal areas ,, ,, ,, ,,
$h_1, h_2, h_3 \ldots$,, heights ,, ,, ,, ,,
$f_1, f_2, f_3 \ldots$,, form factors ,, ,, ,, ,,

and

s, h, f the basal area, height and form factor of the mean tree of the classes thrown together,

then the following equation holds good :—

$$V = n_1 \times s_1 \times h_1 \times f_1 + n_2 \times s_2 \times h_2 \times f_2 + \ldots$$
$$= (n_1 + n_2 + \ldots) \times s \times h \times f.$$

If it is now assumed that $h_1 \times f_1 = h_2 \times f_2 = h_3 \times f_3 = \ldots = h \times f$, then the above equation becomes—

$$n_1 \times s_1 + n_2 \times s_2 + \ldots = (n_1 + n_2 + \ldots)\, s,$$

and

$$s = \frac{n_1 \times s_1 + n_2 \times s_2 + \ldots}{n_1 + n_2 + \ldots} = \frac{S}{N},$$

where S = basal area of all trees of the group, and
N = total number of trees ,, ,,

In words, the basal area of the average or mean tree is equal to the arithmetical mean of the basal area of all trees contained in the group.

The volume of the group is then—

$$V = v \times N,$$

where v represents the volume of the arithmetical mean sample tree with a basal area $= s$.

If no tree can be found with the basal area s, another as near as possible to it is chosen of a section s', and the volume of the group is obtained by the formula :—

$$\mathbf{V} = \frac{\mathbf{v' \times s}}{\mathbf{s'}} \times \mathbf{N} = \frac{\mathbf{v' \times S}}{\mathbf{s'}},$$

since $s \times N = S$ = the basal area of all trees in the group.

If several approximately mean sample trees are taken, the formula changes into the following :—

$$\mathbf{V} = \frac{(\mathbf{v}' + \mathbf{v}'' + \mathbf{v}''' + \ldots) \times \mathbf{S}}{\mathbf{s}' + \mathbf{s}'' + \mathbf{s}''' \ldots}.$$

The above method rests on the assumption that $h_1 f_1 = h_2 f_2 = h_3 f_3 = \ldots = hf$. This, however, is not absolutely correct, though it holds good approximately in regularly grown woods. It follows that the degree of accuracy decreases with the increase in the number of classes which are clubbed together into a group, the least accuracy being obtained by joining all classes into one group. In this latter case, the method is known as "the method of the arithmetical mean sample tree."

Example.—In order to illustrate this and the methods to be described hereafter, one acre of Scots pine wood, 70 years old, was callipered, and eighteen sample trees of various diameters were felled and measured. Only timber down to 3 inches diameter at the small end was included in the account. The following list shows the dimensions and the volumes of the sample trees :—

Number.	Diameter. Inches.	Height. Feet.	Basal Area. Square Feet.	Volume, Solid. Cubic Feet.
1	7·50	37	·307	6·62
2	8·50	44	·394	7·26
3	9·25	56	·467	12·13
4	9·40	46	·482	10·81
5	9·60	50	·503	11·63
6	10·70	40	·624	12·37
7	10·70	64	·624	17·14
8	11·00	57	·660	16·19
9	11·50	56	·721	17·43
10	11·60	58	·734	19·17
11	12·10	48	·799	20·41
12	12·10	62	·799	22·40
13	13·10	63	·936	25·93
14	13·16	56	1·009	21·87
15	15·00	48	1·227	27·79
16	15·00	59	1·227	28·40
17	16·10	63	1·467	38·53
18	17·00	64	1·576	39·50

The appended example illustrates the procedure which has been described above.

General Method of Calculating the Volume of a Whole Wood for an Acre of Scots Pine, 70 Years Old.

A.—Calculation by Inch Classes.

Diameter. Inches.	Number of Trees.	Basal Area. Square Feet.	Sample Trees. Diameter.	Sample Trees. Basal Area.	Sample Trees. Volume. Cubic Feet.	Volume of Inch Class.
8	5	1·75	8·50	·394	7·26	37
9	10	4·42	9·25	·467	12·13	115
10	30	16·36	10·70	·624	17·14	449
11	40	26·40	11·00	·660	16·19	648
12	50	39·27	12·10	·799	22·40	1,101
13	45	41·48	13·10	·936	25·93	1,076
14	30	32·07	15·00	1·227	27·79	726
15	20	24·54	15·00	1·227	28·40	568
16	10	13·96	16·40	1·467	38·53	367
Total	240	200·25	..	..	..	5,087

B.—By Three Groups.

Groups and Inches.	Number of Trees.	Basal Area. Sq. Ft.	Mean Sample Trees. Basal Area.	Mean Sample Trees. Diam.	Real Sample Trees. Diam.	Real Sample Trees. Basal Area.	Real Sample Trees. Volume. Cub. Ft.	Volume of Group.
I. 8, 9, and 10	45	22·53	·503	9·6	9·6	·503	11·63	521
II. 11, 12, 13 .	135	107·15	·799	12·1	12·1	·799	22·40	3,004
III. 14, 15, 16 .	60	70·57	1·176	14·7	15·0	1·227	28·40	1,633
Total . .	240	200·25	..	..	..	..	..	5,158
C.—By the Arithmetical Mean Tree.								
..	..	..	..	..	12·1	·799	20·41	..
..	..	..	..	..	12·1	·799	22·40	..
..	..	..	..	..	13·6	1·009	21·87	..
All inch classes .	240	200·25	·834	12·4	..	2·607	64·68	4,968

2. Modifications of the General Method.

It has been shown above that the volume of a wood is represented by the formula :—

$$V = V_1 + V_2 + V_3 + \ldots = v_1 \times \frac{S_1}{s_1} + v_2 \times \frac{S_2}{s_2} + v_3 \times \frac{S_3}{s_3} + \ldots$$

As long as the fractions $\frac{S_1}{s_1}, \frac{S_2}{s_2}, + \ldots$ differ, the volumes of the sample trees in the several classes or groups should be measured separately and the volume of each class, or group, calculated. In order to shorten the procedure, it has been proposed to fix the number of sample trees so that

$$\frac{S_1}{s_1} = \frac{S_2}{s_2} = \frac{S_3}{s_3} = \ldots c, \text{ a constant.}$$

In that case the above formula reduces to

$$V = (v_1 + v_2 + v_3 + \ldots) \times c.$$

By following this method, the sample trees of the several classes, or groups, can be thrown together and measured in one lot, while the volume of the whole wood is obtained by one calculation. This is a great convenience and saves much time. Based on this principle, a number of modifications of the general method have been elaborated, of which the following may be mentioned :—

a. Draudt's Method.

Draudt took p per cent. of the trees in each class as sample trees, the proportion of these to the total number of trees in each class being $= \frac{p}{100} = \cdot 0p$. He thus obtained the equation

$$V \times \cdot 0p = v_1 \times n_1 \times \cdot 0p + v_2 \times n_2 \times \cdot 0p + v_3 \times n_3 \times \cdot 0p + \ldots$$

The right side of this equation represents the volume of all sample trees equal to, say, v, giving $V \times \cdot 0p = v$ and

$$V = \frac{v}{\cdot 0p} = \frac{v \times 100}{p}$$

It generally happens, however, that the number of sample trees to be taken in each class includes a fraction of one tree. Draudt eliminates these fractions by considering ·51 as a full sample tree and by neglecting ·50 and under. The result of this operation is

that the original proposition is no longer fully maintained ; more-over, some of the classes obtained no sample tree at all, and these are not represented in the calculation. Any degree of inaccuracy thereby caused depends on the total number of trees in the wood. There is no necessity to illustrate the method by an example, as it has been superseded by a further modification, which will be explained in the next paragraph.

b. Urich's Method.

In order to avoid the inaccuracy involved in Draudt's method, Urich proposes to form a number of groups, to allot to each the same number of trees, and to select the same number of sample trees in each group. The diameter of each sample tree should be the arithmetical mean of the group to which it belongs. In this way, the proportion between S and s is the same in each group, and the volume of the wood is, as in Draudt's method, obtained by the formula $V = v \times \frac{S}{s}$. Urich's method is thus a combination of Draudt's method with that of the arithmetical mean sample tree of each group. The degree of its accuracy depends on the number of groups and on the number of sample trees measured in each. The method has the disadvantage that the basal area of the group sample trees must be calculated before they can be selected. Urich proposes to avoid this by estimating the mean diameter of the trees in each group. Experience has shown that the inaccuracy involved in this way is very small. An example of the method will be found on page 54.

c. Robert Hartig's Method.

In the two methods just described, each sample tree represents the same number of trees. As the volume increases rapidly with the increase of the diameter, it follows that a sample tree in a group of small trees represents a much smaller volume than one in a group of large trees. Hartig argues that each sample tree should represent the same volume and not the same number of trees, and he proposes to allot to each group an equal part of the total volume. As the latter is, of course, not known, and as the basal area fairly represents the volume, he allots equal parts of it to each group. He then calculates the basal area and diameter of

Urich's METHOD OF CALCULATING THE VOLUME OF A WHOLE WOOD FOR AN ACRE OF SCOTS PINE, 70 YEARS OLD.

Groups.	Diameters and Number of Trees.	Basal Area.	Mean Sample Tree.		Real Sample Trees.			Volume of Wood.
			B. Area.	Diam.	Diam.	B. Area.	Volume.	
I.	8 = 5	1·75	..	..	..	..	..	..
	9 = 10	4·42	..	..	..	..	..	..
	10 = 30	16·36	..	..	..	..	..	..
	11 = 35	23·10	..	..	9·6	·503	11·63	..
	80	45·63	·57	10·2	10·7	·624	17·14	..
II.	11 = 5	3·30	..	..	..	..	..	..
	12 = 50	39·27	..	..	..	..	..	..
	13 = 25	23·04	..	..	12·1	·799	22·40	..
	80	65·61	·82	12·3	13·1	·936	25·93	..
III.	13 = 20	18·44	..	..	..	..	..	..
	14 = 30	32·07	..	..	..	..	..	..
	15 = 20	24·54	..	..	..	..	..	..
	16 = 10	13·96	..	..	15·0	1,227	27·79	..
	80	89·01	1·11	14·3	15·0	1·227	28·40	..
Total of Wood	240	200·25	..	..	..	5·316	133·29	5,021

There is only one calculation according to the formula :—

$$\text{Volume of the Wood} = \frac{133{\cdot}29 \times 200{\cdot}25}{5{\cdot}316} = 5{,}021 \text{ cubic feet.}$$

the mean sample tree for each group and selects the same number of these for each. The formula for Hartig's method is :—

$$V = v_1 \times \frac{S_1}{s_1} + v_2 \times \frac{S_2}{s_2} + v_3 \times \frac{S_3}{s_3} + \ldots$$

As $\frac{S_1}{s_1}, \frac{S_2}{s_2}, \frac{S_3}{s_3}$ . . . are not of equal value, it follows that, theoretically speaking, the sample trees should be measured and the volume of each group calculated separately. The addition of these volumes represents the volume of the whole wood. So far Robert Hartig. As his method stands, it is inferior to Urich's

Robert Hartig's METHOD OF CALCULATING THE VOLUME OF A WHOLE WOOD FOR AN ACRE OF SCOTS PINE, 70 YEARS OLD.

A.—BY THREE GROUPS.

Groups.	Diameters and Number of Trees.	Basal Area.	Mean Sample Tree.		Real Sample Trees.			Volume of Groups and Wood.
			B. Area.	Diam.	Diam.	B. Area.	Volume.	
I.	8 = 5	1·75	..	..	..	..	..	..
	9 = 10	4·42	..	..	..	..	..	..
	10 = 30	16·36	..	..	..	..	..	..
	11 = 40	26·40	..	..	10·7	·624	12·37	..
	12 = 23	18·05	..	..	10·7	·624	17·14	..
	108	66·98	·62	10·7	..	1·248	29·51	1·584
II.	12 = 27	21·22	..	..	12·1	·799	22·40	..
	13 = 45	41·48	..	..	13·1	·936	25·93	..
	14 = 4	4·27	..	..	..	..	..	..
	76	66·97	·88	12·7	..	1·735	48·33	1,866
III.	14 = 26	27·80	..	..	..	..	..	..
	15 = 20	24·54	..	..	15·0	1·227	27·79	..
	16 = 10	13·96	..	..	15·0	1·227	28·40	..
	56	66·30	1·18	14·7	..	2·454	56·19	1518
Total	240	200·25	..	..	..	..	..	4968

B.—BY ONE GROUP.

By throwing the three groups together, also the six sample trees, and making one calculation for the whole wood, we obtain :—

	240	200·25	..	..	..	5·437	134·03	4936

Formula for calculation :—

$$\text{Volume of Wood} = \frac{134{\cdot}03 \times 200{\cdot}25}{5{\cdot}437} = 4{,}936 \text{ cubic feet.}$$

method because it involves the separate measurement of the sample trees of each group, and requires a number of calculations where only one is required under Urich's method.

The author of this book has found, by trial calculations, that, if the sample trees are selected according to Hartig's method, they

can be thrown together and the volume of the whole wood obtained by one calculation, as in Urich's method, without any appreciable difference in the result, as will be seen by the example on page 55. ~~The correctness of this view is confirmed by the results of the further example on page 64, being a record of the measurement of a wood by the British Forestry Commission.~~

d. Determination of Volume by Form Factors and Volume Tables.

Instead of felling and measuring sample trees, their volume can be ascertained by means of form factors, or taken from volume tables. This applies to all methods. In all these cases the determination of the volume is effected according to the formula :—

$$V = S \times H \times F.$$

How the *basal area* of a tree, class, or wood is ascertained has been shown above.

The *mean height* of a number of trees or of a whole wood is ascertained in various ways, which differ somewhat in their degree of accuracy. The theoretically most accurate way is to obtain it out of the formula :—

$$V = S \times H \times F = s_1 \times h_1 \times f_1 + s_2 \times h_2 \times f_2 + \dots$$

and $$H = \frac{s_1 \times h_1 \times f_1 + s_2 \times h_2 \times f_2 + \dots}{S \times F}$$

This formula necessitates a knowledge of the form factors of all age classes and of the average form factor of the whole wood, which makes the determination of the mean height somewhat complicated. On reference to page 38 it will be seen that, for instance, the form factors for Scots pine, timber only, after the age of 40 years, and up to the age of 120 years, move between ·45 and ·47—in other words, they move within very narrow limits. The British yield tables so far published show equally narrow limits of change. Hence, a comparatively small inaccuracy is involved by assuming that the form factors of the several classes and the average form factor are very nearly of the same amount. This reduces the formula to :—

$$\text{Mean height} = H = \frac{s_1 \times h_1 + s_2 \times h_2 + \dots}{S};$$

in words : "the mean height is equal to the total volume of

cylinders erected over the basal area of the trees divided by the total basal area."

The mean height of a wood can also be ascertained by multiplying the mean height of each class with the corresponding number of trees and dividing the sum total thus obtained by the total number of trees in the wood, the method being expressed by :—

$$H = \frac{n_1 \times h_1 + n_2 \times h_2 + \ldots}{N}$$

If a somewhat smaller accuracy suffices, a number of trees are selected which show about an average diameter and height, their height measured and the mean calculated, which represents the mean height of the class, group or wood, as the case may be. Another way is to take the height of the arithmetically mean tree as the mean height of the wood.

The best method is to construct a " height curve " out of the measurements of a number of trees representing the several diameter classes. Assuming that nine trees selected in that way show the following dimensions :—

Diameter in Inches.	Height in Feet.	Diameter in Inches.	Height in Feet.	Diameter in Inches.	Height in Feet.
8·5	47	11·0	55	13·6	61
9·3	50	11·6	58	15·0	59
10·7	52	12·1	55	16·0	63

By plotting the heights as ordinates over the diameters as abscissæ, Fig. 22 is obtained.

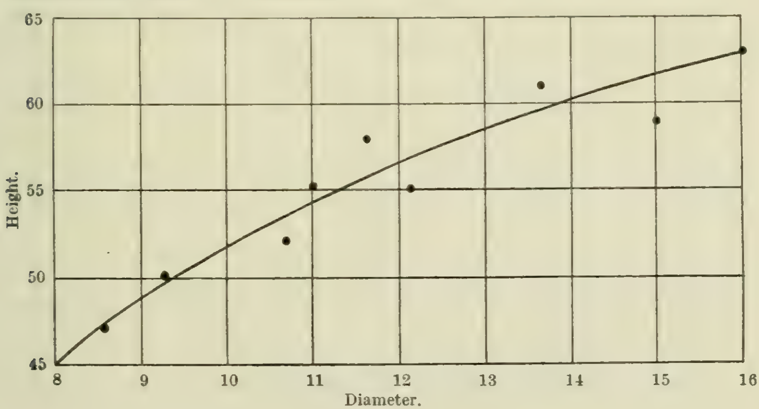


Fig. 22.

From this curve the following values of the heights of the several inch classes are read off :—

Diameter in Inches.	Height in Feet.	Diameter in Inches.	Height in Feet.	Diameter in Inches.	Height in Feet.
8	45	11	54	14	60
9	49	12	56	15	62
10	52	13	58	16	63

By utilizing these data the mean height of the wood can be calculated.

According to the basal area formula :—

$$\text{Mean height} = \frac{1{\cdot}75\times 45+4{\cdot}42\times 49+16{\cdot}36\times 52+26{\cdot}40\times 54+39{\cdot}27\times 56+41{\cdot}48\times 58+32{\cdot}07\times 60+24{\cdot}54\times 62+13{\cdot}96\times 63}{200{\cdot}25} = 57$$

$H = 57$.

According to the number of trees formula :—

$$\text{Mean height} = \frac{5\times 45+10\times 49+30\times 52+40\times 54+50\times 56+45\times 58+30\times 60+20\times 62+10\times 63}{240} = 56$$

$H = 56$.

According to the average of the sample trees :—

$$\text{Mean height} = \frac{47+50+52+55+58+55+61+59+63}{9} = 55 \text{ feet.}$$

According to the heights of the mean sample trees of the inch classes taken from the height curve :—

$$\text{Mean height} = \frac{45+49+52+54+56+58+60+62+63}{9} = 55 \text{ feet.}$$

The form factors must be obtained from form factor tables, if such are available. They are determined by the formula $F = \dfrac{V}{S \times H}$ by measuring large numbers of felled trees whenever fellings are made, and arranging the results into tables according to species, height and age (see page 38).

An example of determining the volume of a wood by form factors is appended (see page 59). The utilization of the form factor

method depends on the existence of form factor tables applicable to a particular locality, as they differ according to the quality of the locality. The form factors for Scots pine (average quality) given on page 38 refer to German woods, and are given as ~~·462~~ ·47 for the wood here under consideration, while the corresponding form factors for Scots pine grown in Scotland are given as ·39 in the yield tables published by the Forestry Commission. The latter are liable to be altered as further data become available.

Calculation of the Volume of One Acre of Scots Pine 70 Years Old By **Form Factors.**

A.—By Inch Classes.

Diameter. Inches. *a*	Number of Trees. *b*	Basal Area, Square Feet. *c*	Average Height. Feet. *d*	Form Factor. *e*	Volume. Cubic Feet. $c \times d \times e$. *f*
8	5	1·75	45	·45	35
9	10	4·42	49	·46	100
10	30	16·36	52	·46	391
11	40	26·40	54	·46	656
12	50	39·27	56	·46	1,012
13	45	41·48	58	·47	1,131
14	30	32·07	60	·47	904
15	20	24·54	62	·47	715
16	10	13·96	63	·47	413
				Total Volume =	5,357

B.—All Inch Classes thrown together into One Group.

8 to 16	240	200·25	56·31	·462	5,210

e. The Volume Table Method.

The method of preparing volume tables for single trees has been explained on page 39. Here the method of utilizing such tables for the determination of the volume of whole woods is dealt with.

Theoretically, volume tables are obtained by multiplying the basal area at height of chest by the average height of the tree and by the form factor. In practice, they are obtained by measuring large numbers of trees whenever fellings offer the necessary opportunities. To be really useful, separate tables should be constructed for different qualities of the locality, the latter being

determined by the height of the trees. Where great accuracy is essential, a further differentiation according to age is required, but this is not necessary for ordinary administrative purposes, such as the preparation of working plans. These tables give average data for the volume of trees of the several diameter classes, and that is just what is wanted in practical forestry. The volume of the whole wood is expressed by the formula :—

$$V = v_1 \times n_1 + v_2 \times n_2 + v_3 \times n_3 \ldots$$

The accuracy of the method should be exactly the same as that obtained by the method of form factors, while it avoids the difficult task of ascertaining the form factors separately.

f. The Yield Table Method.

The method of constructing yield tables is described in Chapter VI. They are tables which give the development of woods from their formation to the time when they are finally cut over, separately according to quality of locality. The volumes given for the several ages are used in determining the volume of growing woods. For that purpose, the forester determines :—

(1.) The quality class of the locality.
(2.) The density of the crop.
(3.) The age of the crop.
(4.) The mean height.

The quality class in this case is best judged by the height growth; the density of the crop is ascertained either by the basal area of the trees on a sample plot, or it is estimated; the age is obtained either by the counting of rings on stumps, or by cutting one or more trees for the purpose, or it may be known from records. Based upon these data the yield can be taken from the yield tables. If, for a given age, the basal area in the table differs from that of the wood, it must be modified accordingly; a second correction may be necessary owing to a difference in height.

Example.—A Scots pine wood 60 years old has a mean height of 53 feet and a density equal to ·8 of full stocking. The appropriate yield tables give the following data :—

Quality Class.	Mean Height at 60 Years.	Volume. Cubic Feet.
I.	67	4,840
II.	57	4,250
III.	46	3,240

The quality of the wood is between II. and III. class, but nearer to II., which has a volume of 4,250 cubic feet; that amount must be reduced in the proportion of 53 : 57, owing to difference of height. As the density of the wood is only = ·8, the remainder must be further reduced in the proportion of .8 : 1, and the volume of the wood $= 4{,}250 \times \frac{53}{57} \times \cdot 8$

$V = 3{,}161$ cubic feet.

In various European countries, where the management of forests has been organised and reliable yield tables have been compiled, the estimation of the volume by such tables is extensively practised, and in some countries (as, for instance, in Hesse-Darmstadt) practically no measurements are made for the preparation of working plans and other administrative purposes; in fact, the volumes are estimated by means of yield tables with such accuracy that the volumes obtained by subsequent fellings agree to a remarkable degree with the previous estimates, in addition to a great saving of work. Hence, the preparation of yield tables cannot be too strongly recommended to all countries where systematic management of the forests is aimed at.

g. The Volume Curve Method.

When no volume table suitable for the locality is available, the forester can construct a curve which gives the volume for the different size classes. He measures a limited number of sample trees, and plots their volumes as ordinates against the corresponding diameters as abscissæ. Between the points thus obtained he draws a mean curve, from which he can read off the volumes of trees of successive diameters, classed according to inches, half inches, or any other unit. Such a curve is called a "*volume curve*," and its data are used for the calculation of the volumes of the different diameter classes and of the whole wood, according to the formula :—

$$\text{Volume of wood} = n_1 \times v_1 + n_2 \times v_2 + n_3 \times v_3 + \ldots\ldots$$

where $n_1, n_2, n_3 \ldots$ represent the numbers of trees in the several classes and $v_1, v_2, v_3 \ldots$ the volumes of the mean trees of the successive size classes taken from the volume curve.

The degree of accuracy of the method depends on the number of measured sample trees used in the construction of the curve and the care with which they are selected. For practical requirements

the number need not be large; generally it is quite sufficient to utilize the number of sample trees which must ordinarily be used under any of the methods described above. The plotting should be done on a large scale, which can then be reduced by photography, so as to bring the points closer together. This facilitates the drawing of the mean curve.

Example.—A Scots pine wood, 70 years old, is found to contain 240 trees per acre, ranging from 8 to 16 inches in diameter at breast height. The following nine trees were selected fairly distributed over the several diameter classes (with a slight excess in the middle classes) showing the following results:—

Diameter. Inches.	Volume. Cubic Feet.	Diameter. Inches.	Volume. Cubic Feet.	Diameter. Inches.	Volume. Cubic Feet.
8·5	7·5	11·0	17·5	13·6	27·0
9·3	12·0	11·6	18·0	15·0	28·0
10·7	14·5	12·1	20·5	16·0	33·0

These results, being plotted in the manner explained above, give the curve shown in Fig. 23:—

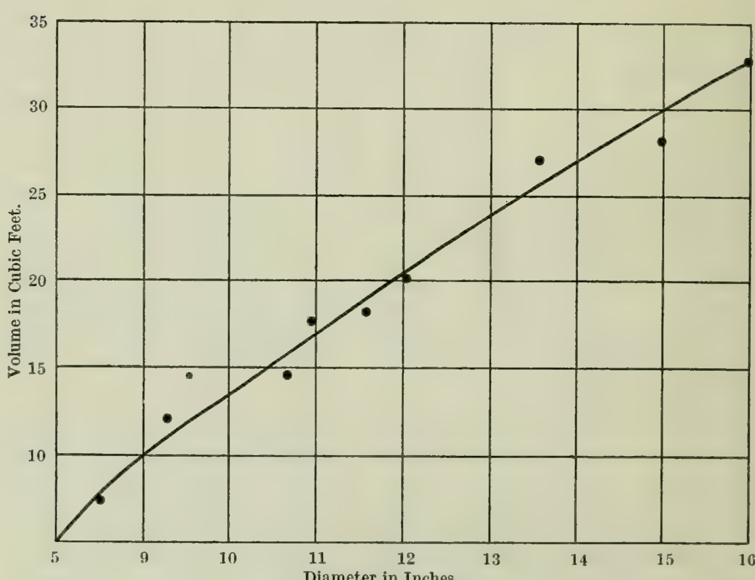


Fig. 23.—Volume Curve.

From this curve, the volumes are read off for successive diameter classes and the volume of the wood calculated, as shown in the following table :—

Diameter. Inches.	Number of Trees in the Class.	Volume of Mean Tree. Cubic Feet.	Volume of Class. Cubic Feet.
8	5	5·0	25
9	10	10·0	100
10	30	13·5	405
11	40	17·0	680
12	50	20·5	1,025
13	45	24·0	1,080
14	30	27·0	810
15	20	30·0	600
16	10	33·0	330
Total	240	..	5,055

h. Block's Method of forming Groups.

Block proposes a new method of forming groups, based on the opinion that the volume of the larger trees should be specially considered, as the smaller trees disappear in the subsequent thinnings. Accordingly, he forms a number of small groups from the largest trees downwards, placing, say, 20 trees per acre in each of the top groups, and an increasing number in the groups containing the smaller trees, with the residue in the last group. He also selects a number of sample trees, decreasing in number from the top downwards ; from these the volume of each group is separately calculated. Block considers his method as specially suited for the periodic measurement of permanent sample plots.

It will be observed that Block favours the larger trees in two ways, by placing a smaller number of trees in them and by allotting more sample trees to them. It appears to the author of this book that this is overdoing the matter unnecessarily. At any rate, owing to the large number of groups and the separate calculation of their volumes, the method involves very much more work than is required in Urich's or Hartig's methods, while experimental measurements seem to show that the increased accuracy, if any, is too small to compensate for the additional work. Moreover, there is nothing to prevent an increase of the number of groups under Urich's or Hartig's method, if it should be con-

sidered desirable; or of giving extra sample trees to the groups of large trees. In the latter case, Urich's method would, however, lose the advantage of measuring up the sample trees in one lot, and of obtaining the volume of the wood by one calculation.

With certain modifications, Block's method has been adopted by the Austrian Forest Research Institute at Mariabrunn, by the Prussian Research Institute at Neustadt-Eberswalde, and also by the British Forestry Commission in the measurement of the volume of permanent sample plots. Of the latter, a short description is given below.

i. The British Forestry Commissioners' Method.

The Commissioners have lately issued a memorandum dealing with the "Permanent Sample Plot Work." The latter is destined to serve for a variety of objects such as :—

(1.) The determination of the volume of the stock at periodic measurements.

(2.) The study of the increment of the plot under a continuous and definite system of management, so as to obtain data for the preparation and improvement of yield tables.

(3.) To compare the development of adjoining sample plots in the same wood under different systems of management, so as to determine the best method of treatment for a particular species under a given set of conditions.

To realise these objects, a very minute method of investigation has been designed, but in this place only the part referring to the determination of the volume of the crop will be mentioned.

The trees in the plot are arranged, according to their girth (alas, not their diameter!), into ½ inch girth classes. They are then allotted to a series of groups in the following ratio :—

Area of Plot.	Number of Group.									
	1	2	3	4	5	6	7	8	9	10
	Number of Trees in each Group.									
·75 acre and over .	50	50	50	50	100	100	100	200	200	200
·3 to ·75 acre .	20	20	20	20	40	40	40	80	80	80
Below ·3 acre .	10	10	10	10	20	20	20	40	40	40

Group 1 contains the largest and Group 10 the smallest trees. The basal area contained in each group is then worked out, as well as that of the average tree. Then, if possible, eight or more sample trees are selected, preferably in pairs, of as near as possible the average girth, height and shape of the class from which they are taken. It is essential that the sample trees should be spread evenly over the range of girth, and that they should, whenever possible, be taken from the surround of, and not within, the plot. The surround should be treated in the same way as the plot.

The calculation of the volume is done for each group separately according to the formula $V = S \times H \times F$. To obtain the data required for these values, the following measurements are taken on each sample tree :—

(1.) Girth at 4 feet 3 inches to the nearest $\frac{1}{2}$ inch.
(2.) Total height to nearest 6 inches.
(3.) Timber height down to 3 inches diameter over bark.
(4.) Girth at half timber height over and under bark.
(5.) Length to lowest living branch $= L\,c =$ lower crown.
(6.) Length to lowest living whorl $= U\,c =$ upper crown.

The crown per cent. is obtained by the formula :—

$$\text{Crown per cent.} = \frac{L - \dfrac{U c + L c}{2}}{L} \times 100, \text{ where } L = \text{total height.}$$

The volumes over and under bark are obtained by multiplying the basal area at half timber height over and under bark respectively by the timber height.

The percentage of bark is obtained by the formula :—

$$\text{Bark per cent.} = \frac{Vol.\,O\,B - vol.\,U\,B}{Vol.\,O\,B} \times 100$$

The form factor is obtained by the formula :—

$$\text{Form factor} = \frac{\text{Volume of tree}}{\text{Total height} \times \text{basal area at 4 feet 3 inches}}.$$

By introducing the volume over bark, or the volume under bark, the value of the form factor over or under bark respectively is obtained.

Calculation of the Group Volumes and the Total Volume.—With the data given above, form factor and height curves are con-

structed. For the former, the form factors of the sample trees are plotted against their respective girths at 4 feet 3 inches, and a curve drawn through the points which express the mean relationship between girth and form factor. Similarly, the total heights of the sample trees are plotted against their girths and a girth height curve drawn. Mean height and form factor for each group are then read off the curves at the point coinciding with the mean girth of each group. The volume is then obtained from the following formula :—

Volume of group = basal area of group × mean height × mean form factor.

The addition of the volumes of the several groups gives the volume of the whole wood.

A useful check on the method (it is suggested in the memorandum) especially where the trend of the form factor graph is doubtful, is obtained by plotting the volumes of the sample trees against the girths at 4 feet 3 inches and drawing a mean curve. The volume of the mean of each group can then be read off the curve and multiplied by the number of trees in the group, giving the volume of the group. These volumes can be compared with those found by the form factor method, and the latter adjusted if necessary. Thus, the volume curve decides in the end and acts as a corrector of any mistakes which may have been made in employing the exceedingly laborious form factor method. After all, it is clear that, if no mistakes are made in employing the latter, the results must be exactly those given by the volume curve method. Would it not save a great amount of work to employ the latter straight away, at any rate for the determination of the volume ?

j. The Form Quotient Method.

Theoretically, the formula $V = S \times H \times F$ gives an absolutely correct expression, but in practice it has drawbacks. The determination of H can be effected by measurements of standing trees, but the determination of F necessitates the felling of a considerable number of trees. If the sample plot has a surround of sufficient size (and this should be the rule) all is well, because the sample trees can be taken from it. If a surround is not available, the sample tree must be taken from the plot itself. This leads to

incomplete stocking, which reduces the value of the statistical enquiry unless trees taken out in thinnings are fit to serve as sample trees. To avoid this drawback, it has been proposed to substitute the form quotient Q for the form factor F.

By form quotient is understood the proportion between the diameter taken at half the total height and the diameter at chest height. The former it is proposed to ascertain, either by measuring the angle between two rays from the eye of the observer directed to the edges of the tree, as well as the distance from the observer to the half-height diameter, or to send a man up for the purpose. To the author's knowledge, there is, except a theodolite, no clinometer fit to give a sufficiently accurate angle, owing to its small size and the possible irregularity of the half-height diameter, while sending up a man in the case of high trees seems altogether outside practical work. Recognising these difficulties, it has been proposed to cut down, after all, one or a few trees, so as to reduce the number of sample trees considerably as compared with the form factor method. But even that appears a doubtful expedient, because, to obtain a reliable form quotient, the cutting down of as many trees as for the construction of a form factor curve would be necessary. In these circumstances, the form quotient method offers no advantages over the form factor method, while it may give less accurate results.

k. Other Methods.

There are quite a number of other methods, some of which involve a very minute procedure; others are only of some theoretical value, and others give only approximate results. It would be going beyond the object aimed at in this book to give detailed accounts of these methods. All those likely to be utilized in the immediate future have been described above.

l. Accuracy and Choice of Method.

In the author's opinion, accuracy in measuring a wood depends far more on the care with which the operation is carried out than on the particular method adopted. Still, there are differences between the various methods.

For the measurement of permanent sample plots, the method of volume tables with 1-inch diameter classes is certainly to be recommended, provided that carefully prepared tables, classified according to quality of locality, height and age are available. In the absence of such tables, the volume curve method is undoubtedly the best substitute. Both methods give averages, and that is exactly what is wanted in statistical records. The method of form factors is, theoretically, just as good, but its application is more complicated and uncertain, unless accurate form factor tables are available. The author cannot find any reason for the adoption of Block's system of forming groups. It is an effort to attain super-accuracy, the realisation of which is doubtful, while it considerably increases the work. If the oldest groups really require some special attention, that can be given to them by allotting extra sample trees to them, instead of disturbing the method of placing the same number of trees in each group.

The determination of the volumes of woods to be used in the preparation of working plans had best be done with data taken from yield tables. The method is quite correct enough for the purpose, and it reduces the work to a minimum. All it requires is a forester sufficiently trained to modify the yield table data correctly, according to local conditions.

In the case of sales of woods, it will generally be wise to work according to the 1-inch diameter class method, with a mean sample tree for each class, using volume tables or volume curves, as the case may be.

For general use, Urich's method of arranging the groups is specially recommended, together with the use of volume tables, if available.

The form quotient method looks attractive at first sight, but, on closer acquaintance, it will be seen that it cannot be brought into the circle of practical politics.

On the whole, it may be said that foresters should aim at the preparation of volume tables and yield tables. This done, the question of forest mensuration will be greatly simplified.

Volume tables should be based on numerous measurements of cut trees, not only of those cut as sample trees, but wherever cuttings are made. The results should be arranged into, say, three qualities—best, middling and lowest—according to height

growth. The trees placed in each quality class should be worked into separate volume tables. Experience will show, whether three classes are sufficient, or whether two additional classes (second and fourth) are required which, in the author's opinion, will not be the case.

3. The Height is not a Function of the Diameter.

If in the case of equal diameters the heights differ considerably, then height classes may have to be formed, in addition to diameter classes. In some cases it happens that the different height classes are separated according to area—for instance, where marked changes in the quality of the locality occur, due to a change in the soil or subsoil, aspect, etc. In such cases the wood is divided into as many parts as there are different height classes, and each part is treated as a separate wood. The booking is done in the same way as that shown on page 46 for different species.

If the different height classes are scattered over the whole area, as in selection forests, the diameter and height must be measured in each case. Where only two height classes are adopted, the height of each tree may be estimated, the diameter measured, and the tree placed in the one or other class. The necessity of forming more than two height classes is rare, except in selection forests. The distinction of height classes generally is a matter of some difficulty; it is necessary only where a very high degree of accuracy is aimed at.

SECTION II.—DETERMINATION OF VOLUME BY MEANS OF SAMPLE AREAS.

1. General.

Instead of measuring all trees in a wood, a certain part of the area may be selected, the volume on it ascertained, and from it the volume of the whole wood calculated. Such a part is called a sample, or type, area. It may be defined as a part of a wood which contains average conditions and especially an average volume of material per unit of area.

Having ascertained the volume of the sample area, that of the whole wood can be calculated in two ways: either according to

area, or according to the number of trees on the sample area and in the wood.

Let $A =$ area of wood,
$a =$ area of sample area,
$V =$ volume of wood,
$v =$ volume of sample area,

then the following proportion is assumed to exist :—

$$v : V = a : A$$

and

$$\mathbf{V} = \frac{\boldsymbol{v} \times \mathbf{A}}{\mathbf{a}}.$$

Again, if

$N =$ number of trees in the wood,
$n =$ number of trees on the sample area,

then

$$v : V = n : N,$$

and

$$\mathbf{V} = \frac{\boldsymbol{v} \times \mathbf{N}}{\mathbf{n}}.$$

In the former case it is necessary to ascertain the areas, and in the latter the number of trees in both sample area and wood. As, however, the counting of all trees gives hardly less trouble than measuring them, the second method yields only a small saving of labour ; it would be adopted only when the area of the wood is not known, or cannot readily be ascertained.

2. Selection of Sample Areas.

The proportion given above will hold good only if the sample area represents a fair average of the whole wood, so that it can be considered as a model of it ; in other words, if a measurement of the trees on it yields an average basal area of stems per unit of area, an average height and the same form factors. The sample areas must be selected accordingly.

Here several cases must be distinguished :—

(*a*.) The quality of the wood is the same throughout the area. In this case, the sample area may be selected anywhere, as long as the density of stocking represents an average. In

very large woods, it may become desirable to take several sample areas and calculate the mean.

(*b.*) Several qualities occur which are clearly separated according to area. In that case, each quality is treated separately, and one or more sample areas taken in each part (Fig. 24).

(*c.*) Several qualities exist which change gradually from one to the others. In this case, the sample area may take the shape of a strip which runs through the whole wood, so as

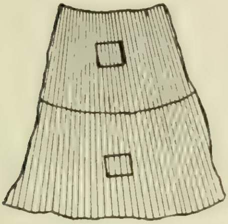


Fig. 24.

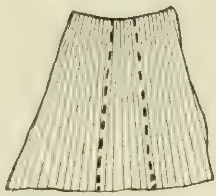


Fig. 25.

to include a due proportion of each quality (Fig. 25). As this is difficult to accomplish, it is generally better to follow the method given under (*b.*), to divide the wood into several parts and to take a sample area in each.

3. Extent and Shape of Sample Area.

The sample area must be of sufficient extent to contain the different classes of trees in the same proportion as the wood. Hence, its size depends on the degree of regularity of the stocking ; the more uniform this is, the smaller may be the sample area. It follows that it may be made smaller in young, fully stocked than in old, irregularly stocked woods.

The absolute extent of the sample area depends on the desired degree of accuracy. In mature woods, it should not be less than 5 per cent. of the whole area, but in young woods it may be less.

Very small sample areas have the disadvantage that proportionately too many trees fall into the boundary lines. The best shape would be that which includes the greatest area as compared with the length of the boundary—in other words, a circle. As this is impracticable, it is usual to give to the sample area the shape of a square, or of a rectangle approaching a square.

4. Measurement of Volume on Sample Areas.

This can be done according to any one of the methods described above. As here a conclusion is drawn from the volume of a small area to that of the whole wood, it is desirable to measure the volume on the sample area as accurately as possible.

5. Merits of the Method of Sample Areas.

The method of sample areas works quickly, and it affords a great saving of time and expense as compared with the measurement of whole woods. On the other hand, its accuracy depends on the degree to which the sample area represents an average of the whole wood. Hence, it only yields accurate results in regular-grown, young and middle-aged woods, less so in old, irregularly stocked areas, or where the quality changes frequently. The method is chiefly useful where extensive areas have to be assessed, or where the value of the produce is small; in fact, where a high degree of accuracy is either impossible to attain or not required. Where only small areas have to be measured, or where the value of a forest has to be ascertained for the purpose of sale, when a high degree of accuracy is wanted, the whole wood should be measured.

SECTION III.—DETERMINATION OF THE VOLUME BY ESTIMATE.

Instead of measuring the trees on the whole or a part of the area, the volume can be estimated in various ways, of which the following deserve to be mentioned :—

1. Estimating the Volume of the Wood as a Whole.

This method, being the oldest and roughest of all, consists of going through the wood and estimating the volume, either of the whole wood, or per unit of area if the total area is known. The estimator must consider differences in the density of stocking, the average volume per tree, the differences in the quality of the locality, and, if for the whole wood at once, its area or number of trees. It stands to reason that the method requires great experience and practice on the part of the estimator, and even then considerable mistakes may be made.

2. Estimating by Trees.

Under this method, each tree is estimated separately, the volume of the wood being obtained by adding together the volumes of the several trees. With great care, an experienced estimator can obtain fairly accurate results, but, if done carefully, the operation takes almost as much time as if the diameters of all trees and the height of some of them are measured ; in the latter case, the volume can be calculated by means of form factors or volume tables, a procedure which yields far more reliable results.

The method is only justified in open woods consisting chiefly of old trees, such as standards in high forest or in coppice with standards, or where a low degree of accuracy meets the requirements of the case. In such cases, the estimate may extend over the whole area, or over a sample area only.

3. Estimating according to the Results of Past Fellings.

Where fellings have been made and the fall accurately measured, the results can be used to estimate the standing crop in similar woods. In such cases, it is necessary to take into consideration any differences in the age, density of stocking, height, etc.

Frequently, fellings made in strips cleared for roads or rides give useful data for estimating the crop of the adjoining woods. In all such cases, the estimate is based on the volume per unit of area.

CHAPTER V.

DETERMINATION OF THE AGE OF TREES AND WOODS.

It is of importance to know, not only the actual dimensions of the trees and their volume, but also the time which has been necessary to produce them. To solve this question, the age of single trees, as well as that of whole woods, must be ascertained.

1. Determination of the Age of Single Trees.

a. Standing Trees.

All trees increase annually in diameter and also by the elongation of the leading shoots and branches, at any rate up to a certain age. The diameter increment produces every year an additional concentric ring, and the new leading shoot leaves marks which are more or less distinguishable according to species and age. These facts yield data by which the age can be determined in the majority of cases, but not in all, when no records are available which give the age. Accordingly, the following methods of determining the age may be distinguished :—

i. Determination from Existing Records.

Reliable records yield the best results, if they refer to individual trees. In the case of trees which form part of a wood, they are not always accurate, as many woods are not even-aged.

ii. Determination by Estimate.

As a general rule, it may be assumed that the larger the tree the older it is. Taking, therefore, into consideration the conditions under which a tree has grown up, its age can be estimated within 10 or 20 years as long as height-growth continues. In the case of very old trees, the limit of accuracy is much wider. At all times, this method requires much practice and experience, and even then it yields only approximately correct results.

iii. Determination by the Number of Annual Shoots.

In the case of species which leave clear marks of the successive annual shoots, the age can be ascertained by counting these shoots from the top downwards and adding a proportionate number of years for the lowest part of the stem, where the marks are no longer distinguishable. This method is, in Europe, only applicable to the various species of pine up to a certain age, less so in the case of firs and not at all in that of larch or of the ordinary broad-leaved species.

iv. Determination by means of Pressler's Increment Borer.

As explained in Chapter I., with this instrument a narrow cylinder of wood can be extracted from the stem, on which the concentric rings may be counted. The instrument does not, however, work satisfactorily beyond a depth of 6 inches, so that the centre can only be reached if the diameter of the tree does not exceed 12 inches. Even then, it is frequently difficult to hit off the centre, as the trees generally grow more or less eccentric.

b. Felled Trees.

By far the best method is to count the concentric rings on a stump, and, if necessary, to fell a tree for the purpose. At the same time this is not always an easy operation, and in some cases it is altogether impracticable. It is easiest in the case of the so-called ring-porey broad-leaved species and in conifers which produce a darker-coloured summer or autumn wood than that formed in spring. Frequently, false rings appear. These may be distinguished from true rings by finding that they do not run right round the tree (Hornbeam, Alder). In the case of suppressed trees, the true rings are frequently so narrow, either all round or in parts, that they are difficult to distinguish.

The business may be facilitated by smoothing the surface, making a slanting cut, or applying colouring matters (as indigo, alizarine ink, Prussian blue, alcohol coloured with aniline, sulphuric acid, etc.). Such colouring does not always produce the desired effect.

The number of rings thus counted represents only the age of the tree above the place where it has been cut. To the number so

obtained, the number of years which the tree took to reach that height must be added. If absolute accuracy is required, the stool must be split open along the centre and the rings counted to the starting-point.

In this way, the *physical* age of the tree can be ascertained, provided that each concentric ring represents a year's growth. It is, however, by no means certain whether this is always the case, as temporary interruptions of growth may cause two rings to be formed in one year, as, for instance, the destruction of the leaves by insects and the subsequent sending forth of a second crop of leaves, fire running through a wood, or even late frost. Moreover, there are trees in the tropics on which the concentric rings cannot be distinguished.

Another point is that a distinction must be made between the *physical* and *economic* age of a tree. By the latter is understood the actual growing age, leaving out of consideration any years during which the tree may have been at a standstill, owing, for instance, to heavy shade from above or unfavourable weather.

2. Determination of the Age of Whole Woods.

a. Even-aged Woods.

If the age of such woods is not known from authentic records, it can be ascertained by determining the age of a tree by one of the methods indicated above. If a tree is felled for the purpose of counting the concentric rings, it is desirable to avoid exceptionally thick trees, as such trees may represent former advance growth.

As whole woods are rarely established in one year, owing to failures and subsequent repairing, or, in the case of natural regenerations, owing to two or more seed years being necessary for the complete stocking of the area, it is generally desirable to examine several trees and take the mean.

b. Uneven-aged Woods.

In many cases, woods are less even-aged than has been indicated above. The differences in the age of the several component parts of the wood may be very considerable, as regeneration may have extended over a long period. In such cases, the mean age must be ascertained.

By the "mean age" of an uneven-aged wood is understood that period which an even-aged wood requires to produce the same volume as the uneven-aged wood.

Let V be the volume of the wood ;
a_1, a_2, a_3 . . . the ages of the several age classes ;
$v_1, v_2, v_3,$ . . . the volumes of the several age classes ;
I, the mean annual increment of an even-aged wood of the same volume as the uneven-aged one ;
A, the mean age, or the age of an even-aged wood of the same volume as the uneven-aged one ;

Then, according to the above definition, the following equation holds good :—

$$v_1 + v_2 + v_3 + \ldots = I \times A,$$

and

$$A = \frac{v_1 + v_2 + v_3 + \ldots}{I} = \frac{V}{I}.$$

As the even-aged and uneven-aged woods are assumed to have the same volume, it follows that I must be equal to the sum of the mean increments of the several age classes of the uneven-aged wood, that is to say :—

$$I = \frac{v_1}{a_1} + \frac{v_2}{a_2} + \frac{v_3}{a_3} + \ldots$$

By substituting this expression for I in the above equation, the latter becomes—

$$\mathrm{A} = \frac{\mathrm{v_1 + v_2 + v_3 + \ldots}}{\frac{\mathrm{v_1}}{\mathrm{a_1}} + \frac{\mathrm{v_2}}{\mathrm{a_2}} + \frac{\mathrm{v_3}}{\mathrm{a_3}} + \ldots} \quad . \quad . \quad . \quad (1.)$$

This formula is known as that of Smalian and C. Heyer. It says in words : The mean age of a wood is obtained by dividing the volume of the whole wood by the sum of the mean annual increments of the several age classes. The method may be simplified by assuming that the age is approximately proportionate to the diameter ; in that case, the diameter classes may be taken as the age classes. The above formula is chiefly used when the age classes are irregularly mixed over the area.

If the age classes are found on different parts of the area, the

following formula may be used, where m_1, m_2, m_3, . . . represent the areas of the several age classes :—

$$\mathbf{A} = \frac{\mathbf{m_1 \times a_1 + m_2 \times a_2 + m_3 \times a_3 + \ldots}}{\mathbf{m_1 + m_2 + m_3 + \ldots}} \quad . \quad (\mathbf{2.})$$

This formula was first given by Gümpel. It gives good results if the differences in age are small and the age itself is close to that at which the increment culminates, as it then changes but slowly.

André bases the calculation upon the number of trees in the several age classes. If they are n_1 ; n_2 ; n_3 ; . . . , his formula runs thus :—

$$\mathbf{A} = \frac{\mathbf{n_1 \times a_1 + n_2 \times a_2 + n_3 \times a_3 + \ldots}}{\mathbf{n_1 + n_2 + n_3 + \ldots}} \quad . \quad (\mathbf{3.})$$

All these formulas are somewhat troublesome. Formula (1) demands a knowledge of the volume and increment ; (2) of the areas occupied by each age class ; formula (3) requires the number of trees in each age class. In practice, the mean age is frequently taken as equal to the average age of the sample trees, or of the age classes, according to the formula :—

$$\mathbf{A} = \frac{\mathbf{a_1 + a_2 + a_3 + \ldots}}{\mathbf{n}} \quad . \quad . \quad . \quad (\mathbf{4.})$$

where n represents the number of sample trees, or age classes, as the case may be.

Finally, the age of the arithmetical mean sample tree can be taken as the mean age of the wood.

Example :—

Let

$v_1 = 4{,}000$	$a_1 = 50$	$m_1 = 2$ acres	$n_1 = 1{,}500$
$v_2 = 9{,}000$	$a_2 = 60$	$m_2 = 3$,,	$n_2 = 1{,}600$
$v_3 = 7{,}000$	$a_3 = 70$	$m_3 = 2$,,	$n_3 = 800$
$v_4 = 4{,}000$	$a_4 = 80$	$m_4 = 1$,,	$n_4 = 300$

Mean age according to formula :—

Years.

$$(1)\ A = \cdot \frac{4{,}000 + 9{,}000 + 7{,}000 + 4{,}000}{\frac{4{,}000}{50} + \frac{9{,}000}{60} + \frac{7{,}000}{70} + \frac{4{,}000}{80}} = \frac{24{,}000}{380} \quad . \quad = 63{\cdot}2$$

$$(2)\ A = \ . \ \frac{2 \times 50 + 3 \times 60 + 2 \times 70 + 1 \times 80}{2 + 3 + 2 + 1} \quad . \quad = 62{\cdot}5$$

$$(3)\ A = \frac{1{,}500 \times 50 + 1{,}600 \times 60 + 800 \times 70 + 300 \times 80}{1{,}500 + 1{,}600 + 800 + 300} = 59{\cdot}8$$

$$(4)\ A = \ . \quad . \quad . \ \frac{50 + 60 + 70 + 80}{4} \quad . \quad . \quad . = 65$$

CHAPTER VI.

DETERMINATION OF THE INCREMENT.

During every growing season, a tree increases by the elongation of the top shoot, side branches and roots, and by the laying on of a new layer of wood and bark throughout its extent. Thus, the height and diameter (or basal area), as well as the spread of the crown, increase constantly up to a certain age, producing an increase of volume called the *increment*. By adding up the increment of the several trees in a wood, that of the whole is obtained.

The increment may refer to one or more growing seasons, and accordingly a distinction must be made between—

(1.) The current annual increment, or that laid on in the course of one year.

(2.) The periodic increment, or that laid on during a number of years.

(3.) The total increment, or that laid on from the origin of a tree or wood up to a certain age, frequently that when the tree, or wood, is cut.

(4.) The mean annual increment, or that which is obtained by dividing the increment laid on during a given period by the number of years in the period. If the mean annual increment is calculated for a portion of the total age, it is called the *periodic* mean annual increment, if for the total or final age of the tree or wood, it is called the *final* mean annual increment.

In determining the increment of whole woods, it must be remembered that a certain number of trees disappear from time to time, owing to thinnings and natural causes. All such removals must be taken into account in determining the total increment produced.

The determination of the increment may refer to the past (backward) or to the future (forward). As the former deals with

actually existing quantities, the determination can be made with a comparatively high degree of accuracy; the latter, on the other hand, is to a considerable extent based on speculation, and, therefore, less reliable.

SECTION I.—DETERMINATION OF THE INCREMENT OF SINGLE TREES.

1. Height Increment.

a. Of the Past.

The height increment of a standing tree can, in some cases, be ascertained by measuring the length of the annual shoots between the whorls formed in successive years. This refers especially to some species of Pinus. In all other cases it is necessary to cut a tree for the purpose of ascertaining the number of years during which a certain length of it has been produced.

In all cases, where a complete knowledge of the height increment during the several periods of life is required, the tree should be divided into a number of sections, the length of which depends on the desired degree of accuracy. The concentric rings are then counted at the end of each section, and, from the data thus obtained, the height of the tree at successive periods of life can be ascertained.

Generally, graphic interpolation gives the best results, as it equalises accidental irregularities. In this case, the abscissæ represent the ages, and the ordinates the corresponding heights. By connecting the points thus indicated by a steady curve, the height at successive ages can easily be read off.

Example.—See analysis of a Scots pine tree, at p. 83.

b. Height Increment of the Future.

The expected height increment for a number of years to come can be estimated from the increment of the immediate past. In doing this, the rate of increment during the past must be studied, and especially the time ascertained when the current annual increment of the species usually culminates. If the increment immediately before the time of inquiry was still rising, it may continue to do so or not, according to whether the maximum has

been reached or not. If it is already falling, it will continue to do so, and in that case the rate at which it is likely to fall must be estimated. In this way, the probable increment for a limited number of years (say 10) can be estimated with satisfactory accuracy. This is best done by constructing a height curve of the past and elongating it for the required period, so as to form a continuous graph.

2. Diameter Increment.

a. Of the Past.

This can refer to wood and bark, or to wood only.

The increment of wood and bark laid on by standing trees can be ascertained by repeated measurements of the same tree, a certain number of years being allowed to pass between every two measurements. The latter are made with the calliper, care being taken to mark the place of measurement without causing an unusual swelling at that part of the tree. Where immediate results are required, the increment can be ascertained with Pressler's increment borer. The number of years for which it can be ascertained depends on the length of the cylinder which can be extracted and on the rate of growth. As most trees grow irregularly, it is necessary to ascertain the increment at opposite sides, or at four sides, and to take the mean. These investigations rest on the assumption that the concentric rings are distinguishable, and that each ring represents one year's growth.

The increment can be ascertained with much greater accuracy by felling a tree and measuring the breadth of the desired number of rings on the section, the latter being laid at right angles to the axis of the stem. The measurements are made with a scale subdivided to a sufficient degree. This is either laid on the section and the breadths read off, or the latter are taken off with a pair of compasses and the dimensions then taken from the scale. In either case, care must be taken to obtain averages by measuring along two, four, or more radii, arranged at equal distances over the section, and then taking the mean of the several readings.

In the case of standing trees, the increment can only be ascertained for a limited number of years. If a tree is felled, the increment can be ascertained for the several periods of its life—

say, for every five, ten, or more years. The result can be graphically represented and a mean curve of increment constructed, from which the increment for any desired intervals can easily be determined. By repeating the above operation at successive heights from the ground, the increment can be ascertained in the several parts of the stem. (See example below.)

b. *Diameter Increment of the Future.*

This is estimated from the increment of the immediately preceding period, taking into consideration how far the future diameter increment may be affected by the method of treatment, more especially the proposed degree of thinning; the stronger the latter, the greater is the increment likely to be.

3. Sectional Area Increment.

The increment in basal area is calculated from that of the diameter. Let D be the mean diameter of the whole section, d the diameter of the same section n years ago, then

Basal increment during n years =

$$\frac{D^2 \times \pi}{4} - \frac{d^2 \times \pi}{4} = \frac{(D^2 - d^2) \times \pi}{4} = (D^2 - d^2) \times \cdot 785.$$

The basal increment can be ascertained for a limited number of years only, or for the several periods of the life of a tree. An estimate of the future increment is based upon that of the immediate past, taking into consideration the proposed treatment, as in the case of the diameter increment.

4. Volume Increment.

a. *Of the Past.*

The past volume increment of a tree during a certain period of years, n, is equal to the difference of volumes at the commencement and end of the period. These volumes can be ascertained by examining a series of sections at various heights of the tree, or by basing the calculation upon measurements made at the middle section, or by using form factors.

i. Determination of the Increment by Sections.

If the increment of only a limited number of years, n, is desired, it can be ascertained by means of the increment borer. The breadth of n rings is ascertained at regular intervals along the stem, and the difference between the present volume and that n years ago calculated.

The investigation of the progress of increment throughout the life of a tree is called a *stem analysis.* It consists of a combination of a height, diameter and volume analysis.

The tree having been divided into a suitable number of sections, each is cut through in the middle, the number of concentric rings counted, and the diameter at the several ages measured. The measurements are best plotted, so that a representation of a longitudinal section through the tree is obtained. For this purpose, the heights of the several cross-sections from the ground are marked on a vertical line, which represents the axis of the stem ; also the heights which the tree had obtained at successive periods of its life. Next, the radii, or diameters, of the cross-sections are marked on horizontal lines, and the points thus obtained connected by a series of graphs, which represent the stem curves at the several stages during the life of the tree. From the data thus obtained, the increment throughout the several periods of the life of the tree can be calculated. As the thickness of the bark at former periods cannot be ascertained, these investigations can refer only to the increment in wood, exclusive of bark.

Example :—

Analysis of a Scots Pine Tree, Stem only.

The tree was cut up into nine pieces, which gave the following cross-sections :—

Section I.	taken	at foot of tree,			showing	97	concentric	rings.
II.	,,	5 feet above ground,			,,	95	,,	,,
III.	,,	15	,,	,,	,,	89	,,	,,
IV.	,,	25	,,	,,	,,	85	,,	,,
V.	,,	35	,,	,,	,,	80	,,	,,
VI.	,,	45	,,	,,	,,	72	,,	,,
VII.	,,	55	,,	,,	,,	64	,,	,,
VIII.	,,	64	,,	,,	,,	34	,,	,,
IX.	,,	68	,,	,,	,,	26	,,	,,

Top = 9 feet long. Total height = 77 feet.

Height of Section. Feet.	Number of Rings.	Number of Years which the Tree took to reach that Height.
0	97	0
5	95	2
15	89	8
25	85	12
35	80	17
45	72	25
55	64	33
64	34	63
68	26	71
77	0	97

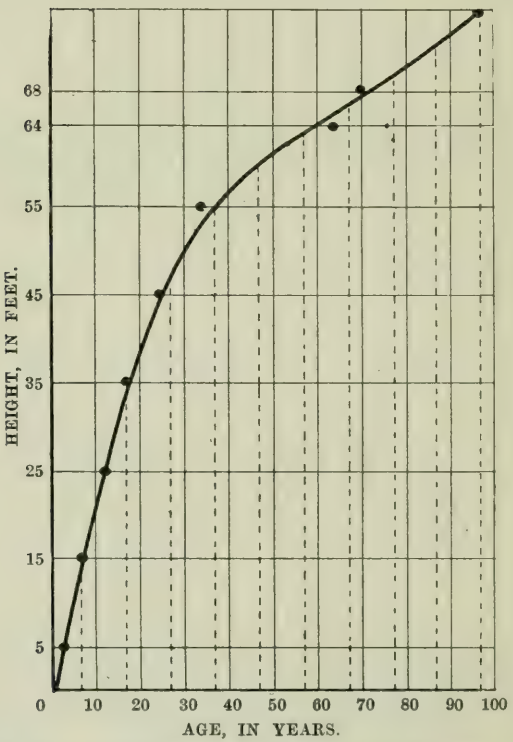


Fig. 26.—Graphic Representation of the *Height* Increment.

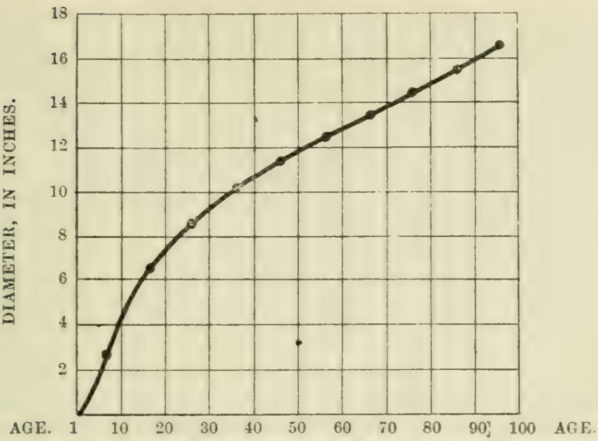


Fig. 27.—Graphic Representation of the *Diameter* Increment at 5 feet from the ground.

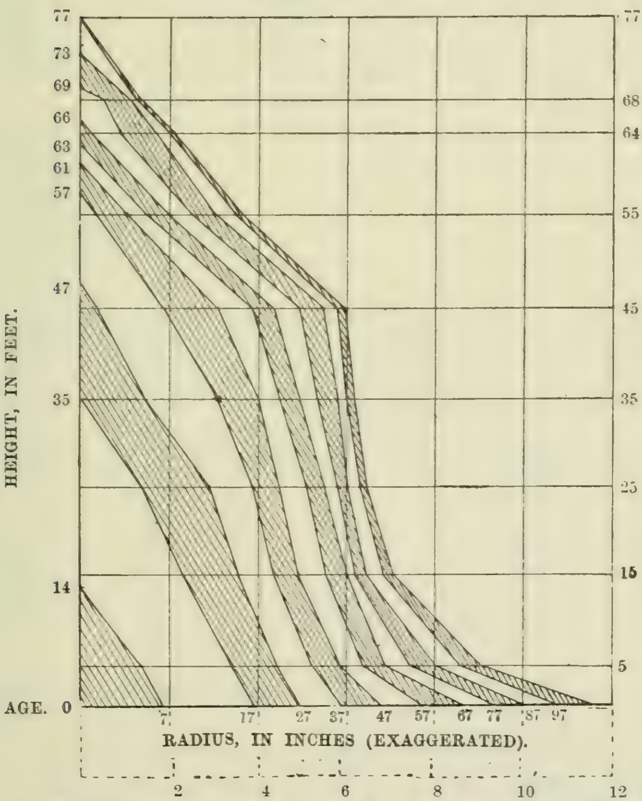


Fig. 28.—Graphic Representation of a *Tree Analysis* (Vertical section of one-half of the Tree).

Radius of Section I. at foot of tree, in Inches.	Radius of Section II. at 5′ from the ground, in Inches.	Radius of Section III. at 15′ from the ground, in Inches.	Radius of Section IV. at 25′ from the ground, in Inches.
Total = 11·50	Total = 8·82	Total = 6·92	Total = 6·38
97 = 10·56	95 = 8·32	89 = 6·78	85 = 6·21
87 = 9·88	85 = 7·86	79 = 6·45	75 = 5·94
77 = 9·22	75 = 7·34	69 = 6·16	65 = 5·62
67 = 8·50	65 = 6·77	59 = 6·04	55 = 5·30
57 = 7·65	55 = 6·25	49 = 5·46	45 = 4·99
47 = 6·71	45 = 5·74	39 = 4·95	35 = 4·41
37 = 5·74	35 = 5·06	29 = 4·24	25 = 3·80
27 = 4·94	25 = 4·34	19 = 3·50	15 = 2·81
17 = 3·83	15 = 3·38	9 = 2·25	5 = 1·30
7 = 1·85	5 = 1·30		
Radius of Section V. at 35′ from the ground, in Inches.	**Radius of Section VI. at 45′ from the ground, in Inches.**	**Radius of Section VII. at 55′ from the ground, in Inches.**	**Radius of Section VIII. at 64′ from the ground, in Inches.**
Total = 6·03	Total = 5·81	Total = 3·54	Total = 2·12
80 = 5·96	72 = 5·75	64 = 3·46	34 = 2·07
70 = 5·71	62 = 5·40	54 = 2·98	24 = 1·66
60 = 5·28	52 = 4·87	44 = 2·40	14 = ·88
50 = 4·80	42 = 4·31	34 = 1·85	4 = ·24
40 = 4·37	32 = 3·74	24 = 1·40	
30 = 3·85	22 = 3·05	14 = 1·03	
20 = 2·95	12 = 1·90	4 = ·41	**Radius of Section IX. at 68′ from the ground, in Inches.**
10 = 1·35	2 = ·35		Total = 1·43
			26 = 1·39
			16 = 1·02
			6 = ·50

CALCULATION OF THE VOLUME OF THE TREE AT DIFFERENT AGES.

Number of Section.	Diameter, in Inches.	Basal Area, in Square Feet.	Length, in Feet.	Volume, in Cubic Feet.	Number of Section.	Diameter, in Inches.	Basal Area, in Square Feet.	Length, in Feet.	Volume, in Cubic Feet.
Whole Tree, including Bark; age = 97 years.					*Whole Tree, without Bark; age = 97 Years.*				
1	17·6	1·69	10	16·9	1	16·6	1·50	10	15·0
2	13·8	1·04	10	10·4	2	13·6	1·01	10	10·1
3	12·8	·89	10	8·9	3	12·4	·84	10	8·4
4	12·1	·80	10	8·0	4	11·9	·77	10	7·7
5	11·6	·73	10	7·3	5	11·5	·72	10	7·2
6	7·1	·27	10	2·7	6	6·9	·26	10	2·6
7	4·2	·10	8	·8	7	4·1	·09	8	·7
Total Timber = 55·0					Total Timber = 51·7				
8	2·9	·05	8/3*	·15	8	2·8	·04	8/3	·12
Total Timber and Fuel = 55·15					Total Timber and Fuel = 51·82				

* The top is considered as representing a cone, the volume of which = basal area × one-third of the height. Minimum size of timber = 3 inches.

CALCULATION OF THE VOLUME OF THE TREE AT DIFFERENT AGES—*cont.*

Number of Section.	Diameter, in Inches.	Basal Area, in Square Feet.	Length, in Feet.	Volume, in Cubic Feet.
		Tree 87 Years Old.		
1	15·7	1·34	10	13·4
2	12·9	·91	10	9·1
3	11·9	·77	10	7·7
4	11·4	·71	10	7·1
5	10·8	·64	10	6·4
6	6·0	·20	10	2·0
7	3·3	·06	8	·5
		Total Timber =		46·2
8	2·0	·02	5/3	·03
		Total Timber and Fuel =		46·23
		Tree 77 Years Old.		
1	14·7	1·18	10	11·8
2	12·3	·83	10	8·3
3	11·2	·68	10	6·8
4	10·6	·61	10	6·1
5	9·7	·51	10	5·1
6	4·8	·13	10	1·3
		Total Timber =		39·4
7	1·8	·02	8	·16
8	1·0	·01	1/3	—
		Total Timber and Fuel =		39·56
		Tree 67 Years Old.		
1	13·5	·99	10	9·9
2	12·1	·80	10	8·0
3	10·6	·61	10	6·1
4	9·6	·50	10	5·0
5	8·6	·40	10	4·0
6	3·7	·07	10	·7
		Total Timber =		33·7
7	2·0	·02	6/3	·04
		Total Timber and Fuel =		33·74
		Tre e57 Years Old.		
1	12·5	·85	10	8·5
2	10·9	·65	10	6·5
3	10·0	·55	10	5·5
4	8·7	·41	10	4·1
5	7·5	·31	10	3·1
		Total Timber =		27·7
6	2·8	·04	10	·4
7	1·0	·01	3/3	·01
		Total Timber and Fuel =		28·11

Number of Section.	Diameter, in Inches.	Basal Area, in Square Feet.	Length, in Feet.	Volume, in Cubic Feet.
		Tree 47 Years Old.		
1	11·5	·72	10	7·2
2	9·9	·53	10	5·3
3	8·8	·42	10	4·2
4	7·7	·32	10	3·2
5	6·1	·20	10	2·0
		Total Timber =		21·9
6	2·1	·02	10	·20
7	·6	·002	1/3	—
		Total Timber and Fuel =		22·10
		Tree 37 Years Old.		
1	10·1	·56	10	5·6
2	8·5	·39	10	3·9
3	7·6	·32	10	3·2
4	5·9	·19	10	1·9
5	3·8	·08	10	·8
		Total Timber =		15·4
6	2·4	·03	7/3	·07
		Total Timber and Fuel =		15·47
		Tree 27 Years Old.		
1	8·7	·41	10	4·1
2	7·0	·27	10	2·7
3	5·6	·17	10	1·7
		Total Timber =		8·5
4	2·7	·04	10	·40
5	1·6	·01	7/3	·02
		Total Timber and Fuel =		8·92
		Tree 17 Years Old.		
1	6·8	·25	10	2·5
2	4·5	·11	10	1·1
		Total Timber =		3·6
3	2·6	·04	10	·40
4	1·2	·01	5/3	·02
		Total Timber and Fuel =		4·02
		Tree 7 Years Old.		
		Total Timber =		0·0
1	2·6	·04	10	·4
2	1·2	·01	4/3	·01
		Total Timber and Fuel =		0·41

Recapitulation.

The stem of the tree had, at the age of 97 years :

A total volume of = 55·15 cubic feet.

Of this was

$$\text{Bark} \begin{cases} = 55{\cdot}15 - 51{\cdot}82 = 3{\cdot}33 \text{ cubic feet.} \\ = 6 \text{ per cent. of total volume.} \end{cases}$$

Leaving

Timber (over 3″ diameter) under bark	=	51·7 cubic feet.
Firewood	=	·12 ,, ,,
Total Timber and Firewood . .	=	51·82 cubic feet.

By graphically representing the volume of wood at the several ages, Fig. 29 is obtained, which, with the previous diagrams, gives the following data :—

Age of Tree.	Height, in Feet.	Diameter under Bark, at 5′ above ground, Inches.	Volume under Bark, in Cubic Feet.	Periodic Increment, for every Ten Years. Cubic Feet.
0	—	—	—	
10	20	4·0	1·8	1·8
20	38	7·4	6·0	4·2
30	51	9·1	12·0	6·0
40	58	10·6	18·0	6·0
50	62	11·9	24·0	6·0
60	64	12·8	29·9	5·9
70	67	13·9	35·3	5·4
80	70	15·0	42·0	6·7
90	74	16·0	48·0	6·0
97	77	16·6	51·8	3·8
			Total......	51·8

ii. Determination of the Increment by the Middle Section.

If somewhat less accurate results suffice, the volumes can be ascertained by multiplying the sectional area in the middle by the height. Let V be the volume of the tree at the present time,

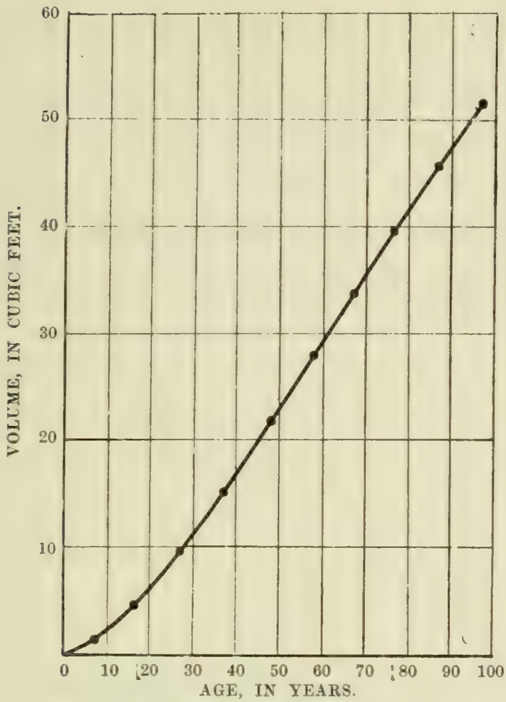


Fig. 29.—Graphic Representation of the *Volume.*

v that n years ago, H and h the corresponding heights (Fig. 30), and S and s the corresponding sectional areas at $\frac{H}{2}$ and $\frac{h}{2}$, then

$$I = V - v = S \times H - s \times h.$$

The height and the sectional area at $\frac{H}{2}$ can easily be measured.

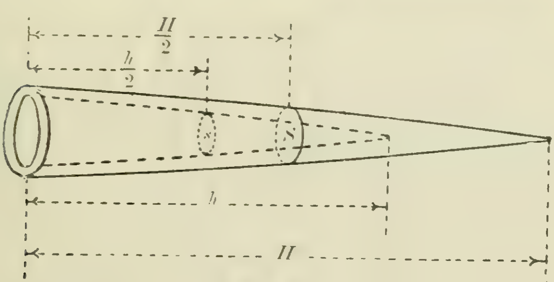


Fig. 30.

The height h, n years ago, if it cannot be ascertained by external marks, is ascertained by cutting off a piece from the top downwards, and repeating the operation, until the point has been ascertained, where the basal area contains n concentric rings; then the sectional area s, at $\frac{h}{2}$, is ascertained. The breadth of the last n rings can be obtained with the increment borer. The diameter increment must be measured in several places around the stem, so as to obtain the mean.

In order to simplify the operation, Pressler proposed to cut off

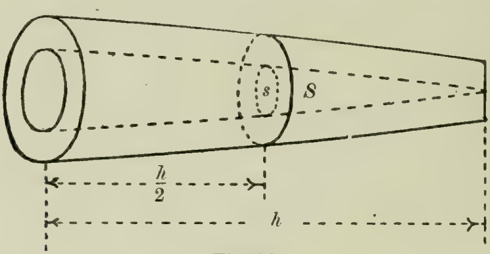


Fig. 31.

a length corresponding to n years' height growth in the first place, and then to measure the sectional area in both cases at $\frac{h}{2}$. (See Fig. 31.) He obtains the increment according to the formula—

$$I = S \times h - s \times h = (S - s)\, h.$$

The error due to omitting the top is said to be compensated for by S being taken somewhat below $\frac{H}{2}$.

iii. Determination of the Increment by Form Factors.

Let S be the basal area of a tree taken at chest height; s the basal area of the tree n years ago taken at the same height; H and h the corresponding heights, and F and f the corresponding form factors, then the increment (Fig. 32)—

$$I = S \times H \times F - s \times h \times f.$$

In the case of a standing tree, H is measured with a height measurer, h is estimated or taken from tables of height growth,

the proportion between the outer and inner diameters being utilised to determine h. S is obtained by measuring the diameter with a calliper, and s with the assistance of an increment borer. F and f must be obtained from form factor tables, or estimated. If F is taken as $= f$, the formula becomes—

$$I = (S \times H - s \times h) \times F.$$

The method can give only approximately correct results, because h has to be estimated. It must not be overlooked that form factor tables give only averages; hence, the method is not adapted to the measurement of a single tree, but only to that of a large number of trees. Even in the latter case, the results can be only approximately correct.

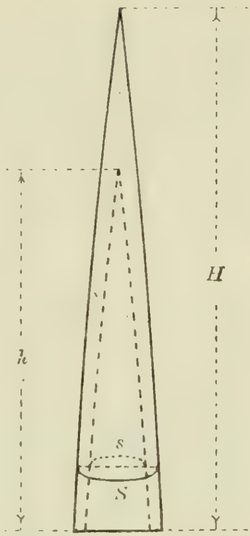


Fig. 32.

b. Volume Increment of the Future.

The increment which a tree may be expected to lay on in the future can be estimated from its own past increment, especially that of the immediate past.

The increment is represented by the formula :—

$$I = S \times H \times F - s \times h \times f,$$

where $s \times h \times f$ represents the present volume, and $S \times H \times F$ that to be expected after n years. The formula shows that, in order to obtain fairly accurate results, it is necessary to estimate S, H and F from s, h and f. How this should be done as regards basal area and height has been explained above. The form factor F may be obtained from tables if such are available; otherwise it must be estimated, or it may be taken as equal to f.

Instead of estimating the separate factors, the volume increment of the next n years may be estimated direct from that laid on during the last n years. In this case, the estimator must consider how far the latter should be modified with regard to the age of the tree, locality, future treatment of the wood, especially the proposed degree of thinning, etc.

According to Pressler's method, the probable increment can be ascertained by estimating the probable diameter increment and then proceeding by the formula—

$$I_n = (S - s)\,h,$$

where s represents the present section in the middle, S the expected section in the same spot after n years, and h the present height. As the method applies only to felled trees, it necessitates the felling of one or more sample trees.

SECTION II.—DETERMINATION OF THE INCREMENT OF WHOLE WOODS.

It has been shown that, in the case of single trees, the accumulation of the volume, as well as the increase of the factors which lead up to it—height, diameter, or basal area increment—can be followed backwards with a considerable degree of accuracy. This is not the case as regards whole woods, because trees die or are taken away in thinnings. Investigations made on sample trees selected in a wood show only the gradual development of the individuals existing at the time of examination, but they throw no light on that of those trees which have disappeared in course of time since the wood was created. Height growth alone makes an exception. An analysis of a number of sample trees will indicate the mean height of these trees during previous periods, which may be taken as the upper height of the wood at those times. These would, of course, not represent the mean heights at the several ages, because until comparatively recent times it could safely be assumed that the now existing trees were, as a rule, amongst the leading trees. This does not, however, always hold good now, as in some cases the majority of the leading trees have been taken out in thinnings, with a view to giving trees of the second height class a chance of developing into leading trees. Whether that system will be maintained is doubtful, since such thinnings made in high forest, except in selection forests, have not always led to satisfactory results. A final decision on the subject will depend on further experience. So far it has been ascertained that the subsequent development of the trees of the second height class has not always corresponded with expectations, leading to a final crop reduced not only in quantity but also in

quality. The total production (final plus intermediate returns) is not increased. It is indeed doubtful whether the early receipts from heavy thinnings will compensate for the reduction in the final crop.

Investigations have proved that the mean height of woods can be deduced from the upper height. For instance, in the case of Scots pine the difference ranges from about 3 to 5 per cent., according to the age of the wood. But no such relation has as yet been found as regards the basal area or the volume ; to evolve the former amounts of these out of the present quantities is more or less speculative. Under these circumstances, one of the two methods about to be described may be followed.

A. Determination of the Future Increment according to the Mean Annual Increment of the Past.

The present volume of the wood is ascertained and divided by its age, the quotient giving the mean annual increment calculated on the growing stock present at the time of measurement. According to the age of the wood, it may be assumed that the mean annual increment will be laid on for a number of years to come, or a somewhat diminished or increased increment.

The method gives fair results, if the calculation is made for the time when the mean annual increment culminates and even for older woods ; it is less accurate in the case of younger woods. Moreover, it is only applicable for a limited number of years.

B. Determination of the Increment by means of Yield Tables.

1. Definition of Yield Tables.

It has already been explained that the progress of height, diameter, basal area and volume increment can be represented by curves constructed on the principle that the successive ages are marked as abscissæ, and that the corresponding ordinates represent the height, diameter, basal area, or volume. Such curves indicate the appropriate quantities for any age up to a certain limit, generally the highest rotation likely to be adopted. From these graphs the data which they represent are read off and arranged in tables, and these are called *Yield Tables*.

By a yield table is understood a tabular statement which gives the course of the development of a wood from early youth up to a certain age, either from year to year, or for intervals of a certain number of years, generally five or ten.

2. Object and Contents of Yield Tables.

Yield tables are used for a great variety of purposes, as :—

(*a.*) Determination of the volume of woods.
(*b.*) ,, ,, ,, increment of woods.
(*c.*) ,, ,, ,, quality of localities or growing stock.
(*d.*) ,, ,, ,, most profitable species, method of treatment, and rotation.
(*e.*) ,, ,, ,, value of the soil, growing stock, or both.
(*f.*) ,, ,, ,, yield of forests.

In order to meet all these requirements, yield tables should show, per unit of area (acre) :—

(1.) The number of trees.
(2.) The mean diameter of trees.
(3.) The basal area of trees.
(4.) The height of the wood.
(5.) The volume which may be found in a fully-stocked wood at successive ages ; also the yield of thinnings.
(6.) The current annual and mean annual increment.
(7.) The form factors.

Separate yield tables must be prepared for—

(*a.*) Each species.
(*b.*) Each method of treatment, as high forest, coppice woods, and combination forest.
(*c.*) Each quality of locality.

The volume is given divided into the different classes of wood, as timber, firewood, etc. The volume of thinnings, or intermediate yields generally, is entered separately from that of final yields.

Yield tables are prepared only for " normal " woods—that is to say, for woods which are fully stocked, taking into consideration the species, quality of locality and the adopted method of treatment. Such woods are produced if no extraordinary

influences have interfered with their progress, such as natural phenomena, faulty treatment, etc.

3. Local and General Yield Tables.

If a yield table has been prepared for a particular district of limited extent, it is called a *local* yield table ; if for a whole province or county, a *general* yield table.

The question, what territorial limits should be assigned to the applicability of a yield table is still under discussion, but so much is certain that, in the preparation of such tables, a considerable extent of country can be thrown together without incurring any appreciable inaccuracy.

4. Quality Classes of Yield Tables.

Localities of different quality, or yield capacity, produce woods which follow in their development different laws. The law of increment of one quality cannot be evolved out of that of the others. The preparation of each yield table should, therefore, be based on data obtained from localities of precisely the same quality. As a rule, however, a large number of different qualities exists ; hence, in practical forestry, some concession must be made by being satisfied with a limited number. These rarely exceed five, and frequently three are quite sufficient. The best quality is generally designated as I. quality, though the reverse would be better.

In proceeding to construct yield tables, it is obviously of the first importance to have a ready method by which the quality of a locality may be determined. It is explained in Silviculture that the several factors of the locality, such as the chemical and physical conditions of the soil and subsoil and the climate, do not enable the forester to determine the quality of the locality for forest purposes with any degree of accuracy, and that the only satisfactory indication is given by the wood which has been produced on it. In other words, a locality which produces, in a given time, a large volume is of good quality ; one which produces a small volume of inferior quality. The volume, then, is in the first place the surest indication of the quality of the locality.

As it is, however, a somewhat cumbrous process to ascertain

the volume when determining the quality, the question arises, whether one or more of the elements, from which the volume is calculated, would not do equally good service. It has been shown above that the volume $V = s \times h \times f$. Of these three elements, the form factor moves between comparatively narrow limits, and it is not suited for the present purpose, apart from the fact that the volume would first have to be ascertained in order to determine the form factor. Basal area and height together give a sure indication of the quality—that is to say, two woods which show the same basal area and height may safely be assumed to have the same volume ; hence, the localities which have produced them would be of the same quality. If only one indicating element is used, the height is preferable to the basal area. While two woods of the same species and equal basal areas may have very different heights, experience has shown that two normal woods of the same height have approximately equal basal areas. It follows that the height is, next to the volume itself, the best indicator of the quality of the locality, and it is easily ascertained. Great height growth means good quality, small height growth inferior quality of locality.

Neither the mean diameter nor the number of trees can be used for the above purpose, as they are not in due proportion to the volume. Nor can the product of the number of trees multiplied by the mean diameter be used.

In these circumstances the quality class of the locality and of the growing wood can be determined, either by the measurement of the volume produced by fully stocked sample plots, or by the rate of height growth.

5. Methods of Constructing Yield Tables.

The following methods have been proposed :—

Annual or Periodic Measurement of the Growing Stock of one and the same Wood; in the second case, the Intermediate Values are found by Interpolation.

The method gives absolute certainty that all data of the yield table are derived from the same quality class, but, as the preparation of the table would take a century and more, the method has only theoretical value. Moreover, accidents may

happen which would render the wood unfit for further observation; hence, several woods would have to be measured.

Annual or Periodic Measurement of the Growing Stock of a limited number of Woods of different Ages.

In order to save time, it has been proposed to select several woods differing in age by a certain number of years, say 20, and to obtain from the measurements of each, extending over 20 years, part of the yield table. To make sure that the quality of the several woods is the same, it is necessary that they should have the same volume at the same age. Supposing 5 woods of the following description are selected:—Plot I. = just started, age 0, volume 0; Plot II. = age 20 years, volume 700 feet; Plot III. = age 40 years, volume 5,500 feet; Plot IV. = age 60 years, volume 9,300 feet; Plot V. = age 80 years, volume 12,000 feet. In this case, Plot I. should reach a volume of 700 feet at the age of 20 years; Plot II. 5,500 feet at 40 years; Plot III. 9,300 feet at 60 years; Plot IV. 12,000 feet at 80 years. If the selected woods develop in a different way, it shows that they do not belong to the same quality class.

Although it is difficult to select on these lines localities which are of exactly the same quality, or woods which will develop in the same manner, there can be no doubt that ultimately satisfactory yield tables can be obtained by observing and periodically measuring suitable woods for a series of years. Hence, the method is actually followed. For each quality class and age gradation, several sample plots are selected, and these are periodically measured and the mean taken. In this way, yield tables will ultimately be obtained. It is necessary to take several plots for each quality and age gradation, so as to obtain average results, and because one or other may become unfit for the purpose in consequence of unforeseen events.

Measurement of a large number of Woods of different Ages once so that Yield Tables are obtained immediately.

Until yield tables, prepared as indicated above, become available, others for immediate use are required. These are obtained by measuring fully-stocked sample plots in a sufficient number of

woods, representing all ages with moderate intervals. Out of the data thus obtained, steady curves and tables are prepared. A separate set of woods is required for each quality class, and the great difficulty consists in selecting for each set localities of the same quality. For this purpose various methods have been suggested, of which the following deserve special mention.

a. Method Based upon an Indicating Wood.

The method is based upon the fact that the older wood has been evolved out of the younger—in other words, that the older wood had at ~~one~~ the same time the same volume as the younger. Hence, it should be possible, by analysing a number of sample trees, to ascertain the volume, or basal area, height and form factor, which the trees of a mature wood had at the several periods of their lives. Guided by the data thus obtained, woods are selected the dominant trees of which show the same dimensions as those which the mature trees had at the same age. Such woods are assumed to give true representations of what the now mature wood was at the same ages. When a sufficient number of woods of various ages have been selected, sample plots with normal stocking are measured in them, and the data worked up into a yield table for the corresponding quality class. The same procedure is followed for all other quality classes.

Various authors have gradually elaborated this system; first Seutter as early as 1799, then Hossfield in 1823. Huber, in 1847, was the first to give a regular method of working with an indicating wood. He calculated the mean tree of a normal, mature wood, analysed it and searched for younger normal woods, the mean trees of which possessed the same dimensions as the mean tree of the mature wood had at the same ages. His method was, however, wrong, because there is no evidence that the mean tree of the mature wood was the mean tree at all former stages of life.

Theodor Hartig, and afterwards Robert Hartig, analysed the largest trees of the mature wood and then searched for younger woods, an equal number of the largest trees of which show the same dimensions as the largest trees of the mature wood had at the same ages. Such woods are considered as having been produced on localities of the same quality, so that they can be used

for the preparation of the same yield table. The system presupposes that the largest trees of the mature wood were amongst the largest trees at all previous periods of the wood's life. Although this holds good generally, exceptions occur. Besides, the method is very troublesome in execution.

b. Baur's Method of Preparing Yield Tables.

After a sufficient number of normal sample plots on localities belonging to various quality classes and stocked with woods of all ages have been carefully measured, the volumes are marked as ordinates over the corresponding ages as abscissæ (Fig. 33).

Next, two curves are drawn, so that the lower touches the lowest points and the upper the highest points indicating these volumes. Then, the area thus confined is divided into as many equal strips as there are quality classes to be distinguished. The woods falling into each strip are considered as belonging to the same quality class. By drawing a mean curve through each strip, the mean volume curve for the quality is obtained, from which the volume table is prepared for successive years. In a similar way, mean curves for the height, basal area and number of trees are constructed for each quality class. The method is of easy application, and it yields good results.

Baur's method has been utilized in the preparation of yield tables for Germany. The work was commenced some 50 years ago, on a prearranged systematic plan, and has led to the compilation of a number of tables. It may be said that the most urgent need of British forestry is the preparation of yield tables, by means of which the results of the industry can be estimated. Until such statistics become available, no substantial progress is likely to be made. Fortunately, the Forestry Commission has taken up the task, and British yield tables for larch, Scots pine and spruce have already been published in the Commission's *Bulletin*, No. 3.

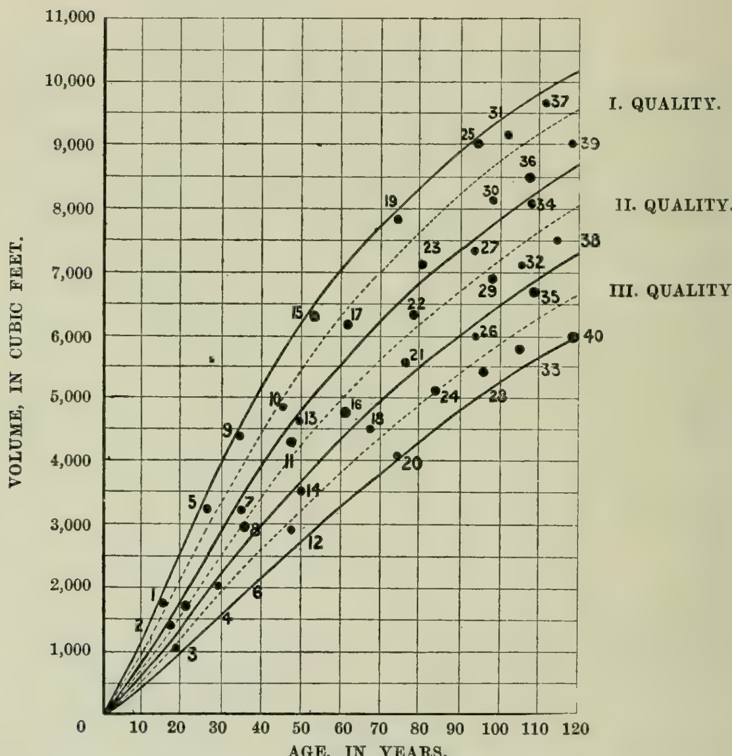


Fig. 33.—Graphic Representation of the *Volume per Acre* of 40 different Woods and their allotment to Three Quality Classes, according to Baur's method.

EXAMPLE OF PREPARING A YIELD TABLE ACCORDING TO BAUR'S METHOD.

Scots Pine: 3 Quality Classes to be distinguished.

Woods Measured as follows:—

No.	Age. Years.	No. of Trees.	Basal Area, sq. ft.	Mean Height, feet.	Volume in solid cub. ft.	No.	Age. Years.	No. of Trees.	Basal Area, sq. ft.	Mean Height, feet.	Volume in solid cub. ft.
1	15	..	62	16	1800	21	76	295	173	70	5500
2	17	..	60	14	1400	22	79	265	177	72	6300
3	18	..	61	13	1100	23	81	245	192	86	7200
4	21	..	84	20	1700	24	85	290	156	62	5030
5	27	1400	130	33	3300	25	94	190	196	93	9000
6	29	2400	99	25	2050	26	94	240	150	67	6000
7	34	1480	133	35	3250	27	94	218	177	80	7300
8	35	1670	113	32	2800	28	96	248	150	69	5300
9	35	910	156	46	4450	29	97	200	176	82	6950
10	46	620	165	55	4800	30	99	170	194	93	8200
11	47	740	150	47	4230	31	104	160	192	94	9200
12	48	860	132	40	2900	32	106	169	177	86	7150
13	49	680	154	52	4700	33	106	220	160	69	5700
14	50	750	132	44	3500	34	108	173	179	86	8100
15	54	450	182	69	6400	35	109	210	152	72	6700
16	62	450	169	65	4700	36	109	151	196	96	8500
17	62	369	184	73	6200	37	112	148	194	98	9700
18	68	420	148	56	4450	38	115	150	176	88	7500
19	74	270	192	83	7800	39	118	145	194	98	9000
20	74	350	146	61	4000	40	120	186	157	75	6000

WOODS SEPARATED INTO QUALITY CLASSES. (FIG. 33.)

No.	Age.	No. of Trees.	Basal Area.	Mean Height.	Volume
			I. Quality.		
1	15	..	62	16	1800
5	27	1400	130	33	3300
9	35	910	156	46	4450
10	46	620	165	55	4800
15	54	450	182	69	6400
17	62	369	184	73	6200
19	74	270	192	83	7800
23	81	245	192	86	7200
25	94	190	196	93	9000
30	99	170	194	93	8200
31	104	160	192	94	9200
36	109	151	196	96	8500
37	112	148	194	98	9700
39	118	145	194	98	9000
			II. Quality.		
2	17	..	60	14	1400
4	21	..	84	20	1700
7	34	1480	133	35	3250
8	35	1670	113	32	2800
11	47	740	150	47	4230
13	49	680	154	52	4700
16	62	450	169	65	4700
21	76	295	173	70	5500
22	79	265	177	72	6300
27	94	218	177	80	7300
29	97	200	176	82	6950
32	106	169	177	86	7150
34	108	173	179	86	8100
38	115	150	176	88	7500
			III. Quality.		
3	18	..	61	13	1100
6	29	2400	99	25	2050
12	48	860	132	40	2900
14	50	750	132	44	3500
18	68	420	148	56	4450
20	74	350	146	61	4000
24	85	290	156	62	5030
26	94	240	150	67	6000
28	96	248	150	69	5300
33	106	220	160	69	5700
35	109	210	152	72	6700
40	120	186	157	75	6000

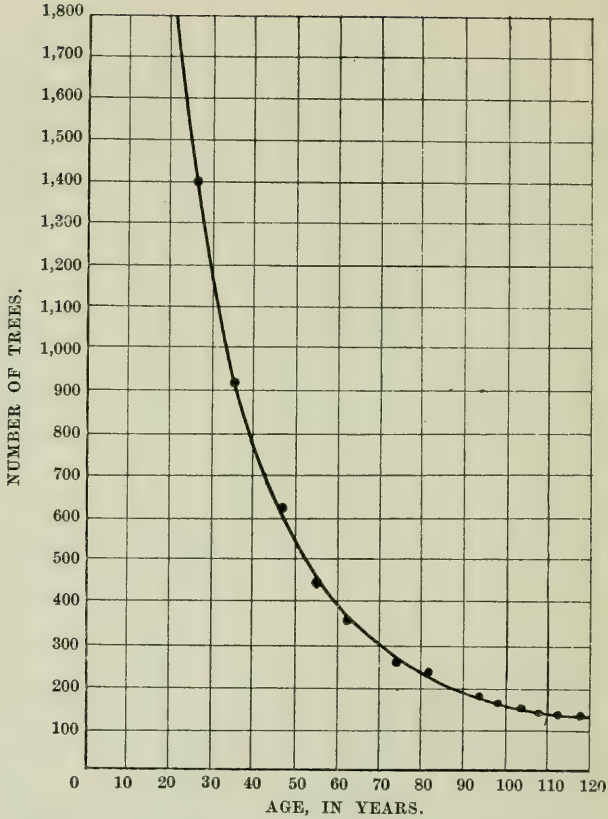


Fig. 34.—Graphic Representation of the *Number of Trees* per Acre.

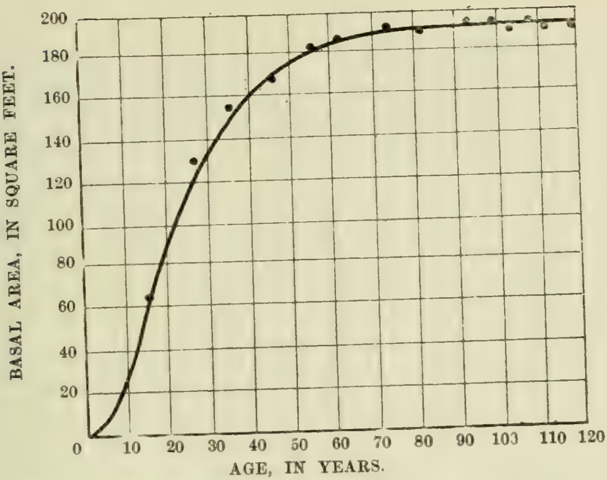


Fig. 35.—Graphic Representation of the *Basal Areas* per Acre.

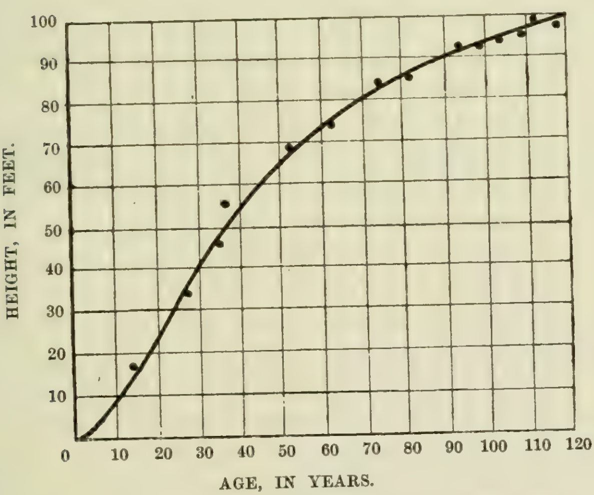


Fig. 36.—Graphic Representation of the *Height Growth.*

YIELD TABLE FOR THE SCOTS PINE, I. QUALITY.

Derived from the Curves in Figs. 33, 34, 35 and 36.

Age.	Number of Trees.	Basal Area. Square Feet.	Mean Height. Feet.	Volume. Cubic Feet, Solid.	Increment.	
					Current. Annual Cubic Feet.	Mean. Annual Cubic Feet.
10	..	30	10	900	90	90
20	2000	92	23	2100	120	105
30	1200	133	40	3300	120	110
40	770	160	54	4500	120	112
50	520	175	64	5400	90	108
60	380	186	73	6250	85	104
70	300	190	80	6950	70	99
80	250	192	86	7600	65	95
90	200	193	90	8200	60	91
100	160	194	94	8650	45	86
110	150	194	97	9100	45	83
120	140	194	100	9500	40	79

c. The British Forestry Commission's Method.

Before the appointment of the Commission in 1919, Mr. R. L. Robinson, then of the Agricultural Department, had commenced the collection of statistics required for the preparation of British yield tables. This work was at once taken up by the Commission, of which Mr. Robinson had become the technical member. While in most of the Continental yield tables the determination of the quality class was based upon the volume per acre produced in a certain number of years, the Commission found that a different method was required in the case of British yield tables, because the available number of normally stocked sample plots was very limited. Most of the British woods had been inefficiently treated, and more particularly the thinnings had either been too heavy or been neglected, so that the quality class could not be determined by the volume on the ground. In these circumstances, the Commission decided to effect the division into quality classes by means of the mean height growth of the woods, as that is closely connected with the volume production and comparatively little affected by the different methods of treatment. The sample plots were classified according to the height of the crop at a standard age, for which 50 years was selected in the case of coniferous woods, which were, to begin with, under considera-

tion. In this the Commission was guided by the following reasons :—

(1.) By the time a coniferous wood has reached the age of 50 years, the producing factors of the locality should have found decisive expression in the crop, so that the height growth would be an indication of the productive power of the locality. Exceptions might occur, but their number would be small.

(2.) As there were only a small number of suitable old woods available, it was not desirable to fix the age higher than 50 years, so as to secure a sufficient number of sample plots.

(3.) It was decided that every 10 feet of height growth at the age of 50 years should represent one quality class, and that the mean height should be a multiple of 10 feet. The mean height thus gives the name to the class. For instance, the 70 feet class represents all woods between 65 and 75 feet.

Example.—The best quality class of larch in Britain is the 80 feet class, which means that the mean wood of this class attains a height of 80 feet in 50 years, the upper and lower limits being 85 and 75 feet respectively. Similarly the 70 feet class runs from 75 to 65 feet, with a mean of 70 feet, and so on down to 35 feet. In this way, the following quality classes were formed :—

For Larch and Norway Spruce :

I.	Quality	class	(80 feet)
II.	„	„	(70 „)
III.	„	„	(60 „)
IV.	„	„	(50 „)
V.	„	„	(40 „)

For Scots Pine :

I.	Quality	class	(60 feet)
II.	„	„	(50 „)
III.	„	„	(40 „)

The sample plots of 50 years of age and over are allotted to their respective classes by means of age-height curves, prepared for each sample plot from the sectional analysis of three sample trees. The next step is to construct a mean age-height curve for each class out of all woods assigned to the class. These mean quality curves are drawn to pass through the heights of 80, 70 and 60 feet at 50 years. The combined graphs are then completed by interpolating a limiting curve between each pair of mean curves. These limiting curves pass through the heights of 85, 75 and 65 feet at 50 years.

It may be asked, whether an equally satisfactory classification of qualities would not be obtained if the mean heights of the woods were plotted as ordinates over the ages as abscissæ in the same way as volumes are plotted in Baur's method ? The adoption of such a plan would certainly save a considerable amount of labour.

The younger plots below 50 years of age which, owing to the nature of the classification, cannot be used for constructing the quality classes, are assigned to the classes to which they belong.

Example.—A Larch plot 30 years old and 46 feet high falls between the 65 and 75 feet limiting lines, and thus belongs to the 70 feet class.

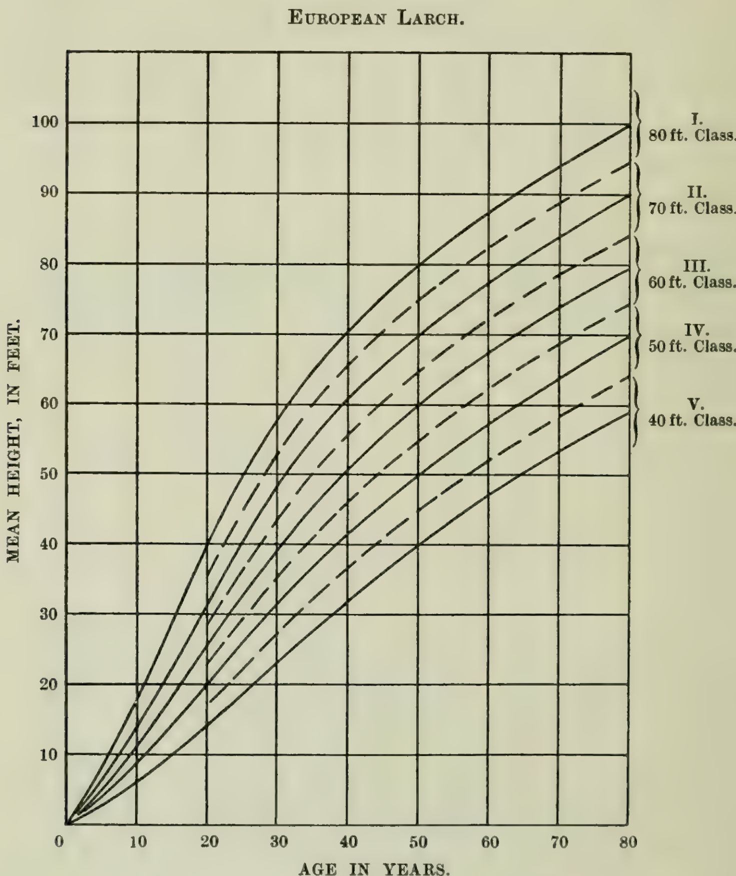


Fig. 37.—Diagram showing Quality Classes of European Larch.

The several plots are then measured, and the obtained data worked up into yield tables in a manner similar to that followed in the case of Baur's method described above.

So far only yield tables for larch, Norway spruce and Scots pine have been published in the Forest Commission's *Bulletin* No. 3, together with some preliminary tables for Douglas fir, Corsican pine, Japanese larch and some notes on other species. Additional tables will, no doubt, follow in due time. The tables for larch and Norway spruce refer to Great Britain and Ireland, but separate tables have been considered necessary in the case of Scots pine for England and for Scotland for reasons which are not altogether convincing.

6. Determination of the Increment of Woods by Means of Yield Tables.

If yield tables are available, and it is desired to estimate the increment of a wood forward or backward, it is necessary to decide in the first place which of the quality classes of the tables corresponds with that of the given wood; in other words, it must be ascertained to which quality class the wood belongs.

The best way of doing this is to measure the volume of a normal sample plot in the wood and compare it with the volumes given in the tables for the same age and the different quality classes. If it agrees with one of these volumes, the two are of the same quality class, and the increment shown in the table applies also to the wood in question.

If the volume of the wood does not agree with any of the volumes in the tables, then that quality class is selected which comes nearest to it, and the increment is ascertained in proportion to the two volumes. Let v_a be the present volume of the wood, V_a the nearest volume given in the table; V_{a+n} the volume given in the same table for the year $a + n$; and v_{a+n} the required volume of the wood in the year $a + n$, then the following equation may be assumed to hold good (see Fig. 38) :—

$$V_a : v_a = V_{a+n} : v_{a+n} \text{ and } v_{a+n} = V_{a+n} \times \frac{v_a}{V_a}$$

and

$$I = \text{Increment in } n \text{ years} = v_{a+n} - v_a = \frac{V_{a+n} \times v_a}{V_a} - v_a$$

$$\mathbf{I} = \boldsymbol{v}_{\mathbf{a}}\left(\frac{\mathbf{V}_{\mathbf{a+n}}}{\mathbf{V}_{\mathbf{a}}} - \mathbf{1}\right).$$

This method rests upon the assumption that the selected yield table correctly represents the progressive increment of the wood

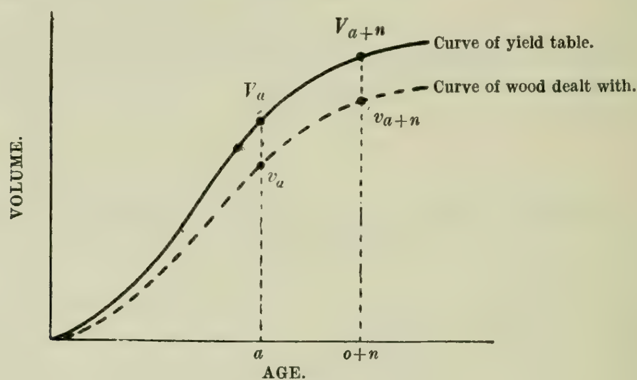


Fig. 38.

of which the increment is to be ascertained. As this is only approximately the case, the degree of accuracy of the method depends—

(*a*.) On the degree to which v_a approaches V_a,

(*b*.) On the difference of ages, that is to say, the difference between a and $a + n$; the smaller this is, the more accurate will be the result.

In following the above method, it is essential to measure the volume on a "normal" sample plot, because only then can the true quality class be ascertained by means of the volume. If no fully stocked sample plot is available, that nearest to it should be selected, and the proportion between the actual and normal stocking ascertained. The actual volume must then be augmented in the same proportion, before it is used for the determination of the quality class and the selection of the yield table. At the same time, this procedure is subject to errors, as it is not always easy to determine correctly the proportion between the actual and normal stocking.

Generally, the method is better adapted to woods which have passed middle age than to younger woods, as in the latter the factors of the locality have not in all cases found full expression. In the case of very young woods, it is altogether useless to measure the volume for the purpose of selecting the proper yield table. For such woods, the quality class must be determined by means of an older wood growing in the vicinity on a locality of similar quality ; the same procedure is followed in the case of blanks. If no such older wood is available, the soil and climate must be examined and the best possible estimate of the quality made accordingly.

As the measurement of the volume takes much time, and as it is difficult to estimate the exact proportion between the actual and normal stocking, it has been proposed to select the proper yield table for a wood by means of one factor of the volume. It has already been explained that of all such, as number of trees, diameter, form factors, basal area and height, the last is the most suitable. Indeed, actual investigation has proved that, in the case of all woods of middle age and upwards, the volume of two woods, other conditions being the same, is fairly proportionate to their mean heights. The mean height is, therefore, an excellent indication of the quality class ; it, as well as the age, is comparatively easy to ascertain. In selecting the appropriate yield table, the mean height is used in the same way as has been described for the volume. If the height agrees with one of the heights given in the yield table for the same age, the increment can be read off directly. If it differs, the nearest is selected and the increment of the table modified in proportion to the difference between the actual height and that given in the table. Should, moreover, the wood not be fully stocked, then the increment given in the table must be further modified in the manner indicated above.

The height by itself is no true indicator of the quality for very young woods ; for such, as well as for blanks, other woods growing in the vicinity must be utilized, or the soil and climate examined.

Example.—A Scots pine wood has a height of 53 feet when 60 years old, and a volume of 3,800 cubic feet; find the probable increment for the next ten years.

YIELD TABLES.

Quality.	Height at 60 years.	Volume in the Year 60.	Volume in the Year 70.
I.	73	6,960	
II.	52	4,660	5,070
III.	30	2,170	

The wood belongs to the II. Quality.
According to the formula—

$$I_n = (v_{a+n} - v_a) \times \frac{h_a'}{h_a} \times \frac{v_a'}{v_a}$$

$$I_{60-70} = (5{,}070 - 4{,}660) \times \frac{53}{52} \times \frac{3{,}800}{4{,}660} = 341 \text{ cubic feet.}$$

The British Forestry Commission, in accordance with its method of classifying the woods used in the construction of its yield tables, determines the quality class to which any wood belongs entirely by the mean height. If, for example, a larch wood 40 years old has a mean height of 58 feet, it falls within the 70 feet class. If there is a difference between the yield table height curve and that of the wood under consideration, a correction must be made in a manner similar to that indicated above.

As regards the use of yield tables generally for the purpose of determining the future increment, it must be remembered that the yield tables give data representing averages obtained from extensive investigations. Hence, they may give amounts, if used for a single wood, which differ somewhat from actuals ; their full usefulness is secured only when applied to a number of woods, when such differences compensate each other. In some Continental countries the accuracy of yield tables has reached such a high degree that, for the purpose of working plans, their data are at once accepted without further corrections as soon as the quality class has been determined in accordance with the height growth of each wood. Experience has shown that any possible difference between forecast and actuals is well below the percentage of error to which operations of this kind are always subject.

PART II.

FOREST VALUATION.

FOREST VALUATION.

FOREST Valuation deals with a variety of subjects, such as :—

(1.) The determination of the value of forest soil, the growing stock and the forest as a whole.

(2.) The determination of the financial results of forestry and of all matters connected therewith.

(3.) The determination of the most profitable method of treatment of forests.

These matters must be determined in cases of sale, partition and assessment of forests for taxation. The soil and the growing stock also form the principal part of the capital invested in forestry, on which the financial results depend. In order to deal with the matters here contemplated, it is necessary to explain the various methods according to which the value of property may be ascertained, to determine the rate of interest applicable to the forest industry, to give certain formulas for calculating with compound interest and to explain the methods of estimating receipts and expenses. All these matters will be dealt with in a preliminary chapter.

The subject of forest valuation has been arranged under the following headings :—

CHAPTER I.—PRELIMINARY MATTERS.
,, II.—THE METHODS OF CALCULATION.
,, III.—THE FINANCIAL RESULTS OF FORESTRY.
,, IV.—EXAMPLES OF APPLICATION.

CHAPTER I.

PRELIMINARY MATTERS.

SECTION I.—THE VALUE OF PROPERTY GENERALLY.

Property means an object which serves for the satisfaction of a requirement. The degree of utility of a property indicates its value. The latter may present itself in various ways. A piece of property may possess value, because it can be used for a certain purpose, such as an article of food, or for the production of another kind or class of property, such as a set of carpenter's tools, or raw materials consumed in various industries.

Again, the value of a property may be general or special; the former is that which a property has in the open market; the latter is that which it has for a particular person, such as a piece of land situated in the middle of another estate; or the value may be due to special conditions, such as an article of food in a famine-stricken district.

By the price of a property is understood the amount of another class of property which is offered for it in exchange; the ordinary means of exchange is money.

The value of property can be ascertained in various ways, of which the following may be specially mentioned:—

(1.) The Sale Value, or the price which can be realised by the sale of the property; if the sale is open to general competition, the sale value becomes the Market Value, which depends on supply and demand.

(2.) The Cost Value, or the total outlay on the acquisition or production of a property.

(3.) The Rental Value, by which is understood the capital corresponding to the rental which the property is capable of yielding; it is commonly expressed by a certain number of years' purchase.

(4.) The Expectation Value, by which is understood the present net value of all yields which a property may be able to give; it is determined by discounting to the present time

all incomes derivable from the property and deducting from them the present value of all expenses to be incurred for the realisation of the incomes.

The expectation value represents the economically correct value of a piece of property ; the drawback, however, is that its determination depends on the estimate of future returns and expenses.

SECTION II.—THE RATE OF INTEREST APPLICABLE TO FORESTRY.

In determining the value of a property, all calculations must be made with compound interest, as all money, whether capital or interest, is capable of again yielding interest. Hence, the determination of the rate of interest applicable to an industry is of the first importance.

Compound interest is applied in the case of forestry, which, from a financial point of view, is an industry like any other commercial undertaking. The producing capital in forestry is, theoretically, the cost value of the forest. As this is in many cases difficult to ascertain, especially in State forests, the market value should be substituted for the cost value. Neither the application of simple interest or a special reduction of the per cent. is admissible, as it would lead to wrong conclusions, nor could the results of forestry be compared with those of other industries.

By rate of interest is understood the proportion between the yearly interest (I) and the capital (C) which has yielded it, as represented by the formula :—

$$\text{Rate of interest} = \frac{I}{C}.$$

By rate per cent., or shortly per cent., is understood the yearly interest yielded by a capital of 100 ; hence :—

$$\text{Per cent. } p = \frac{I}{C} \times 100.$$

The rate of interest applicable to an industry depends chiefly on :—

(1.) The degree of security of the investment and the safety with which it yields a return. In a general way it may be said

that the rate of interest should be inversely proportional to the safety of the investment.

(2.) The supply of, and demand for, capital, which change from time to time and with the locality.

(3.) The general credit of the country in which the industry is carried on—in other words, the interest yielded by Government securities (called Consols in Britain).

It follows that the rate of interest applicable to an industry cannot be a fixed quantity. In the case of forestry, the following points must be considered :—

(*a.*) The safety of capital invested in forests. The soil offers a high degree of security, but the growing stock is subject to damage by man, animals, especially insects, fungi, wind, snow, rime and, above all, by fire, drought and frost. The degree of danger differs much according to species, method of treatment, length of rotation, climate, etc., but the extent of damage can be kept within narrow limits by careful management.

(*b.*) The price of forest produce is, on the whole, less subject to sudden fluctuations than the value of money.

(*c.*) Compared with the cultivation of field crops, it should be noted that forests, once placed under systematic management, yield annually equal returns of produce, while those of agricultural lands differ much according to the season, and that forests require much less labour.

(*d.*) Temporary high prices can be fully utilized in the case of forests by cutting more than the normal yield for a time, or *vice versâ*.

Bearing these matters in mind, attempts have been made to determine the rate of interest applicable to the forest industry in various ways, such as the following :—

(1.) Determination based upon the rate of interest obtainable in agriculture. This is frequently justified, although differences exist between the two methods of using the soil, which frequently are difficult to estimate.

(2.) Determination based on the rate of interest yielded by Government securities. This rate of interest may be too high in some States and too low in others. The method is justified in well-regulated States.

(3.) Determination based upon the relation between the rental and the capital value of the forest. This method is practicable only if—

(*a.*) The annual rental of the forest is accurately known ;

(*b.*) The forest is, at any rate approximately, in such a condition that it can yield a steady annual return.

In practice, these conditions are difficult to fulfil, except in the case of the strictly annual working.

(4.) Determination of the mean annual forest per cent. by placing the market value of the soil equal to the expectation value of the soil calculated from future returns and expenses. This method will be explained after the manner of determining the expectation value has been given.

SECTION III.—USEFUL FORMULAS.

1. Arithmetical and Geometrical Series.

These are useful auxiliaries in forest valuation.

The arithmetical series is built up by starting with an initial term, a, and adding a fixed quantity, q, to every succeeding term. Let $a = 6$ and $q = 3$, the series would consist of $6 + 9 + 12 + 15 + 18 + 21 \ldots$, and the sum of the series would be $S = (6 + 21) \times \frac{6}{2} = 81$; in words: the sum of an arithmetical series is = the sum of the first + the last term × by half the number of terms.

The geometrical series consists of an initial term, which is multiplied by a fixed quantity to form the successive terms, as :—

$$S = a + a \times q + a \times q^2 + a \times q^3 + \ldots + a \times q^{n-1}.$$

With a view to obtaining a formula for the sum, the above equation is multiplied on both sides by q, becoming :—

$$S \times q = a \times q + a \times q^2 + a \times q^3 + a \times q^4 + \ldots + a \times q^n.$$

Deducting the first equation from the second, the result is, after reduction :—

$$S \times q - S = a \times q^n - a, \text{ or } S\,(q - 1) = a\,(q^n - 1),$$

and

$$S = \frac{a(q^n - 1)}{q - 1}.$$

Example :—

$$S = 6 + 18 + 54 + 162 + 486 + 1458 = 2184,$$

or

$$S = \frac{6(3^6 - 1)}{3 - 1} = \frac{6 \times 728}{2} = 2184.$$

The above formula is suitable for the summation of both rising and falling series, but a more convenient formula for falling series is obtained by multiplying the enumerator and denominator in the above formula by -1, thus obtaining $S = \frac{a(1 - q^n)}{1 - q}$.

This becomes for an indefinite series, as $q^\infty = 0, : S = \frac{a}{1 - q}$.

2. The Amount or Future Value.

A capital C_o, put out at p per cent. compound interest accumulates in the course of n years to the value of—

$$C_n = C_o \times 1{\cdot}0p^n, \textit{ or } \log. C_n = \log. C_o + n \times \log. 1{\cdot}0p \quad . \quad \text{(I.)}$$

In this case the following equation holds good :—

$$C_o : C_1 = 100 : 100 + p$$

and $$C_1 = C_o \times \frac{100 + p}{100} = C_o \left(1 + \frac{p}{100}\right) = C_o \times 1{\cdot}0p.$$

Again, $C_1 : C_2 = 100 : 100 + p$ and $C_2 = C_1 \left(\frac{100 + p}{100}\right) = C_o \times 1{\cdot}0p^n$

and ultimately $C_n = C_o \times 1{\cdot}0p^n$, as above.

Example.—A sum of £5 has been expended in planting an acre of land with Scots pine, which is expected to be ready for pit timber at the age of 40 years. To what amount will the £5 have increased, if the money was taken out of an investment yielding 4 per cent. interest ?

$$\text{Log. } C_{40} = \log. 5 + 40 \times \log. 1{\cdot}04$$

Log. 5 = ·6989700 ; 40 × log. 1·04 = 40 × ·0170333 = ·6813320.
Log. C_{40} = log. (·6989700 + ·6813320) = log. 1·3803020 = £24 0*s.* 1*d.*
By using the table in Appendix I. the use of logarithms will be avoided, as $C_{40} = 5 \times 4{\cdot}801$ = £24 0*s.* 1*d.*

3. Discount or Determination of the Present Value.

The present value C_o of a capital C_n to be realised n years hence is $C_o = \frac{C_n}{1{\cdot}0p^n}$, or $\log. C_o = \log. C_n - n \times \log. 1{\cdot}0p$ . . . (II.)

Example.—The final crop of a Scots pine wood at the age of 40 years is expected to be worth £50. What is its value at the present time ?

$$(p = 4 \text{ per cent.}) \log. C_o = \log. 50 - 40 \times \log. 1{\cdot}04$$

Log. $C_o = 1{\cdot}6989700 - {\cdot}6813320 = 1{\cdot}0176380$; and $C_o =$ £10 8*s.* 2*d.*

By using the table in Appendix I. we obtain $C_o = 50 \times {\cdot}2083 =$ £10 8*s.* 2*d.*

4. Summation of Rentals.

a. Future Values.

A rental R becomes due for the first time after m years and is payable altogether n times at intervals of m years ; its value at the end of $m \times n$ years is :—

$$C_{mn} = R + R \times 1{\cdot}0p^m + R \times 1{\cdot}0p^{2m} + \ldots R \times 1{\cdot}0p^{(n-1)m}.$$

Here the first term a is $= R$, and $q = 1{\cdot}0p^m$; hence :—

$$C_{mn} = \frac{R\,(1{\cdot}0p^{mn} - 1)}{1{\cdot}0p^m - 1} \quad . \quad . \quad . \quad . \quad . \quad \text{(III.)}$$

Example.—A sum of £10 is due after 10 years and again every 10 years, altogether eight times ; its value at the end of 80 years, calculated with 3 per cent. interest, will be—

$$C_{80} = \frac{10\,(1{\cdot}03^{80} - 1)}{1{\cdot}03^{10} - 1} = \frac{10 \times 9{\cdot}6409}{{\cdot}3439} = £280 \quad 6s. \quad 9d.$$

A rental R is due at the end of each year altogether n times . its value is obtained by placing $m = 1$ in Formula III.—

$$C_n = \frac{R\,(1{\cdot}0p^n - 1)}{{\cdot}0p} \quad . \quad . \quad . \quad . \quad . \quad \text{(IV.)}$$

Example.—A shooting rent of 4 shillings per acre is obtained during 80 years, payable at the end of each year; calculating with 3 per cent., the accumulated value at the end of 80 years is $C_{80} = \frac{\cdot 2 \times 9\cdot 6409}{\cdot 03} =$ £64 5*s.* 5*d.*

b. Present Values.

A rental R becomes due for the first time after m years, and is payable altogether n times after intervals of m years; its present value is—

$$C_o = \frac{R}{1\cdot 0p^m} + \frac{R}{1\cdot 0p^{2m}} + \ldots + \frac{R}{1\cdot 0p^{nm}}.$$

Here $$a = \frac{R}{1\cdot 0p^m} \text{ and } q = \frac{1}{1\cdot 0p^m}.$$

Hence $$C_o = \frac{\frac{R}{1\cdot 0p^m}\left[1 - \left(\frac{1}{1\cdot 0p^m}\right)^n\right]}{1 - \frac{1}{1\cdot 0p^m}}$$

which, after reduction, leads to

$$C_o = \frac{R\,(1\cdot 0p^{mn} - 1)}{1\cdot 0p^{mn}(1\cdot 0p^m - 1)} \quad . \quad . \quad . \quad . \quad . \quad \text{(V.)}$$

This formula can also be obtained by discounting Formula III. down for mn years.

A rental R is due at the end of every year altogether n times; its present value is—as $m = 1$:

$$C_o = \frac{R\,(1\cdot 0p^n - 1)}{1\cdot 0p^n \times \cdot 0p} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(VI.)}$$

Example.—If the general expenses of management per acre of forest amount to 6 shillings annually, and if that amount is spent during 80 years, the present value, calculating with 3 per cent., and using the table in Appendix I., amounts to $C_o = 6 \times 30\cdot 2008 = 181\cdot 2$ shillings $=$ £9 1*s.* 2*d.*

A rental R is due at the end of each year for ever; its present value is—

$$C_o = \frac{R}{1\cdot 0p} + \frac{R}{1\cdot 0p^2} + \frac{R}{1\cdot 0p^3} + \ldots + \frac{R}{1\cdot 0p^\infty}.$$

Here $$a = \frac{R}{1{\cdot}0p}, \text{ and } q = \frac{1}{1{\cdot}0p}.$$

Hence $$C_o = \frac{\frac{R}{1{\cdot}0p}}{1 - \frac{1}{1{\cdot}0p}} = \frac{R}{{\cdot}0p} \quad . \quad . \quad . \quad . \quad (\text{VII.})$$

Example.—If the annual costs of management, 6 shillings, have to be incurred for ever, their present value, calculated with 3 per cent., comes to $C_o = \frac{6}{{\cdot}03} = 200$ shillings, as compared with 181 shillings during the first 80 years. If the calculation is made with 5 per cent. interest, the respective numbers would be 120 and 117·6 shillings respectively, showing practically a negligible difference.

A rental R is due after n years and again every n years for ever; its present value is—

$$C_o = \frac{R}{1{\cdot}0p^n} + \frac{R}{1{\cdot}0p^{2n}} + \ . \ . \ . + \frac{R}{1{\cdot}0p^{\infty}}.$$

As $$a = \frac{R}{1{\cdot}0p^n}, \ q = \frac{1}{1{\cdot}0p^n}$$

$$C_o = \frac{\frac{R}{1{\cdot}0p^n}}{1 - \frac{1}{1{\cdot}0p^n}} = \frac{R}{1{\cdot}0p^n - 1} \quad . \quad . \quad . \quad . \quad (\text{VIII.})$$

Example.—A larch wood worked under a rotation of 70 years gives a final yield of £180 every 70 years for ever; the present value, calculating with 3 per cent., and using the table in Appendix I., comes to :—

$$C_o = \frac{180}{1{\cdot}03^{70} - 1} = 180 \times {\cdot}1446 = £26 \ 0s. \ 7d.$$

A rental R is due after m years and again every n years for ever; its present value is—

$$C_o = \frac{R}{1{\cdot}0p^m} + \frac{R}{1{\cdot}0p^{m+n}} + \frac{R}{1{\cdot}0p^{m+2n}} + \ . \ . \ . + \frac{R}{1{\cdot}0p^{\infty}}.$$

Here $$a = \frac{R}{1{\cdot}0p^m}; \ q = \frac{1}{1{\cdot}0p^n}.$$

Hence $$C_o = \frac{\dfrac{R}{1{\cdot}0p^m}}{1 - \dfrac{1}{1{\cdot}0p^n}} = \frac{R \times 1{\cdot}0p^{n-m}}{1{\cdot}0p^n - 1} \quad . \quad . \quad \text{(IX.)}$$

Example.—A thinning worth £10 is made in the year 30 of the first rotation of 100 years, again in the year 130, and again every 100 years for ever; its present value is, p being 3 per cent.:—

$$C_o = \frac{10 \times 1{\cdot}03^{70}}{1{\cdot}03^{100} - 1} = 10 \times 7{\cdot}9178 \times {\cdot}0549 = \text{£4 } 6s.\ 11d.$$

A rental (or payment) is due now and again every n years for ever; its present value is:—

$$C_o = R + \frac{R}{1{\cdot}0p^n} + \frac{R}{1{\cdot}0p^{2n}} + \ldots + \frac{R}{1{\cdot}0p^{\infty}}$$

$$C_o = \frac{R}{1 - \dfrac{1}{1{\cdot}0p^n}} = \frac{R \times 1{\cdot}0p^n}{1{\cdot}0p^n - 1} \quad . \quad . \quad . \quad . \quad \text{(X.)}$$

Example.—An acre of land is planted now at a cost of £5, and again every 80 years for ever; the present value of all these payments, with $p = 3$ per cent., is—

$$C_o = 5 \times 10{\cdot}6409 \times {\cdot}1037 = \text{£5 } 10s.\ 4d.$$

5. Conversion of Intermittent into Annual Rentals.

The conversion is effected by multiplying the capital value of the intermittent rental by ${\cdot}0p$.

Examples.—Placing Formula VIII. equal to Formula VII., we obtain:—

$$\frac{R}{1{\cdot}0p^n - 1} = \frac{r}{{\cdot}0p}, \text{ and the Annual Rental } r = \frac{R}{1{\cdot}0p^n - 1} \times {\cdot}0p.$$

Again, Formula IX. = Formula VII.:—

$$r = \frac{R \times 1{\cdot}0p^{n-m}}{1{\cdot}0p^n - 1} \times {\cdot}0p.$$

All the above-mentioned formulas can be solved by means of logarithms or with the assistance of tables, such as those given in Appendix I. The latter give the values for Formulas I., II., VI. and VIII.; they suffice for all ordinary calculations.

SECTION IV.—ESTIMATES OF RECEIPTS AND EXPENSES.

An estimate of the future receipts and expenses is required for the purpose of determining the probable financial returns of foresty. It should be made with great care on the basis of local investigation and the results in the past.

1. Receipts.

Foresters divide the receipts into two classes—namely, (1) those from major or principal, and (2) from minor or accessory produce. The former include all yields of wood whether timber or firewood, while minor produce comprises all other items. Bark is generally included in timber, but if it is severed from the wood before disposal, it is sometimes classed as minor produce. Major produce is obtained partly from final cuttings (final yields) and partly from thinnings (intermediate yields).

Major Produce.—The local investigations include the measurement of existing woods, if any, and the determination of their volume, age, height, current and mean annual increment. If a sufficient number of suitable woods of various ages are available, future returns can be estimated with fair accuracy. If the number of local woods is deficient, or if none are available, the character of the soil and climate must be ascertained and an estimate made of the yield capacity, or quality class. By means of such an estimate and with the help of suitable yield tables, a local yield table is prepared, with which the best possible selection of the appropriate quality class is effected.

The data in the yield table, modified to suit local conditions, are then converted into money values based on the local prices of the several classes of timber and firewood, thus producing a so-called "Money Yield Table."

Minor Produce.—The amounts and values of these items must be ascertained locally.

2. Expenses.

The expenses comprise a variety of items, such as the cost of administration, protection, formation, tending of growing woods, harvesting of produce, construction of roads and other means of

Money Yield Table for **Larch** based on Measurements recorded in the Forestry Commissioners' *Bulletin*, No. 3.

Age. Years.	Mean Height. Feet.	Mean Girth at 4′ 3″. Inches.	Yield, c′.		Net Value of Returns.					Age. Years.
			Final.	Thinning.	Per c′, Pence.		Value per Acre, Shillings.			
					Final.	Thinning.	Final.	Thinning.	Total.	
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*
				First Quality.						
10	18	7	300	..	3	..	75	..	75	10
20	40	16	1,560	80	6	4	780	27	807	20
30	58	24	2,900	265	7	5	1,692	110	1,802	30
40	71	30	3,880	465	8	6	2,587	232	2,819	40
50	80	36	4,570	560	9	7	3,427	326	3,753	50
60	87	41	5,130	645	10	8	4,275	430	4,705	60
70	94	46	5,630	615	11	9	5,161	461	5,622	70
80	100	49	6,070	460	12	10	6,070	383	6,453	80
				3,090				1,969		
				Second Quality.						
10	14	..	200	..	3	..	50	..	50	10
20	31	13	900	60	6	4	450	20	470	20
30	48	20	2,100	210	7	5	1,225	87	1,312	30
40	61	27	3,050	380	8	6	2,033	190	2,223	40
50	70	33	3,700	460	9	7	2,775	268	3,043	50
60	77	38	4,250	510	10	8	3,545	340	3,885	60
70	84	43	4,760	525	11	9	4,363	394	4,757	70
80	90	47	5,170	410	12	10	5,170	342	5,512	80
				2,555				1,641		

transport, the construction of houses, taxes, etc. All these must be ascertained locally. It is customary to deduct the cost of harvesting at once from the receipts and to enter only the net amount into the account.

3. Samples of British Money Yield Tables.

Money yield tables play an important part in forest valuation. They must be based upon measurements in the forest, and an exact knowledge of local conditions, more especially of the prices of produce ruling in the localities to which the valuation refers. Until quite recently, only Continental yield tables were available,

MONEY YIELD TABLE FOR **Larch** BASED ON MEASUREMENTS RECORDED IN THE FORESTRY COMMISSIONERS' *BULLETIN*, No. 3.

Age. Years.	Mean Height. Feet.	Mean Girth at 4′ 3″. Inches.	Yield, c′.		Net Value of Returns.					Age. Years.
					Per c′, Pence.		Value per Acre, Shillings.			
			Final.	Thinning.	Final.	Thinning.	Final.	Thinning.	Total.	
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*
					THIRD QUALITY.					
10	11	..	150	..	..	..	..	..	..	10
20	26	10	560	..	3	..	140	..	140	20
30	39	17	1,460	70	6	4	730	23	753	30
40	51	23	2,290	235	7	6	1,336	117	1,453	40
50	60	29	2,910	360	8	7	1,940	210	2,150	50
60	67	34	3,440	400	9	8	2,580	267	2,847	60
70	74	39	3,910	430	10·5	9	3,421	322	3,743	70
80	79	44	4,300	360	12·0	10	4,300	300	4,600	80
				1,855				1,239		
					FOURTH QUALITY.					
10	9	..	100	..	..	..	..	..	..	10
20	20	..	450	..	..	..	..	..	..	20
30	31	13	900	100	3	2	225	17	242	30
40	41	20	1,570	200	6	4	785	67	852	40
50	50	25	2,160	240	7	5	1,260	100	1,360	50
60	57	30	2,660	260	8	6	1,773	130	1,903	60
70	64	36	3,100	350	9	7	2,325	204	2,529	70
80	69	40	3,470	325	10	8	2,892	217	3,109	80
				1,475				735		

most of them having been prepared for German, Austrian and Swiss conditions. The preparation of these tables was commenced many years ago on a uniform plan, and many of them have now been brought to such a state of perfection that in the case of systematic management future returns can be estimated without any further detailed measurements in the forest. Copies of such tables were published in previous editions of this Volume, as samples. They have also been used by some British foresters with such modifications as differences in climate and other conditions demanded.

Now we have for the first time reliable volume yield tables,

MONEY YIELD TABLE FOR **Scots Pine** IN SCOTLAND, BASED ON MEASUREMENTS RECORDED IN THE FORESTRY COMMISSIONERS' *BULLETIN*, No. 3.

Age. Years.	Mean Height. Feet.	Mean Girth at 4′ 3″. Inches.	Yield, c′.		Net Value of Returns.					Age. Years.
			Final.	Thinning.	Per c′, Pence.		Value per Acre, Shillings.			
					Final.	Thinning.	Final.	Thinning.	Total.	
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*
					FIRST QUALITY.					
10	13	4	200	..	..	..	..	..	..	10
20	26	10	800	100	2	1	133	8	141	20
30	40	18	1,940	150	3	2	485	25	510	30
40	51	25	3,120	280	4	3	1,040	70	1,110	40
50	60	31	4,100	370	5	4	1,729	123	1,852	50
60	67	36	4,840	455	6	5	2,420	190	2,610	60
70	72	41	5,440	510	7	6	3,173	255	3,428	70
80	77	46	5,920	500	8	7	3,937	292	4,229	80
90	81	50	6,350	400	9	8	4,762	267	5,029	90
100	84	53	6,720	210	10	9	5,600	158	5,758	100
				2,975				1,388		
					SECOND QUALITY.					
10	10	..	..	..	..	..	..	..	..	10
20	20	..	..	..	..	..	..	..	..	20
30	31	15	1,300	100	3	2	325	17	342	30
40	41	21	2,480	150	4	3	827	37	864	40
50	50	27	3,450	220	5	4	1,437	73	1,510	50
60	57	32	4,250	270	6	5	2,125	112	2,237	60
70	62	38	4,880	350	7	6	2,847	175	3,022	70
80	67	42	5,400	400	8	7	3,600	233	3,833	80
90	71	46	5,880	385	9	8	4,410	257	4,667	90
100	74	49	6,200	330	10	9	5,167	247	5,414	100
				2,205				1,151		

prepared from numerous actual measurements of woods and sample plots in Great Britain and Ireland. The work was commenced before the War by the forestry branch of the Board of Agriculture, under the direction of Mr. R. L. Robinson (now the technical Commissioner of Forestry) by the establishment and periodic measurement of sample plots. When the War caused extensive cuttings, steps were taken to measure the crops on as many areas as possible, and the results of all measurements were worked up into volume yield tables for larch, Scots pine and Norway spruce. The number of woods and sample plots measured

Money Yield Tables for **Norway Spruce**, based on Measurements recorded in the Forestry Commissioners' *Bulletin*, No. 3.

Age. Years.	Mean Height. Feet.	Mean Girth at 4′ 3″. Inches.	Yield, c′. Final.	Yield, c′. Thinning.	Net Value of Returns. Per c′ Pence. Final.	Per c′ Pence. Thinning.	Value per Acre, Shillings. Final.	Value per Acre, Shillings. Thinning.	Value per Acre, Shillings. Total.	Age. Years.
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*
				First Quality.						
10	12	..	..	..	..	..	..	..	..	10
20	31	..	..	..	..	..	..	..	..	20
30	51	23	3,500	410	2	1·5	583	51	634	30
40	66	33	5,250	925	3	2	1,312	154	1,466	40
50	80	42	6,760	960	4	3	2,253	240	2,493	50
60	91	50	8,020	860	5	4	3,342	287	3,629	60
70	100	55	8,960	665	6	5	4,480	277	4,757	70
				3,820				1,009		
				Second Quality.						
10	10	..	..	..	..	..	..	..	..	10
20	27	..	..	..	..	..	..	..	..	20
30	43	20	2,840	300	2	1·5	473	37	510	30
40	58	30	4,490	540	3	2	1,122	90	1,212	40
50	70	38	5,890	700	4	3	1,940	175	2,115	50
60	79	46	6,940	670	5	4	2,892	223	3,115	60
70	87	53	7,800	565	6	5	3,900	235	4,135	70
				2,775				760		
				Third Quality.						
10	9	..	..	..	..	..	..	..	..	10
20	22	..	..	..	..	..	..	..	..	20
30	36	16	2,140	200	2	1·5	357	25	382	30
40	49	25	3,680	400	3	2	920	67	987	40
50	60	33	4,930	550	4	3	1,643	137	1,780	50
60	68	41	5,910	430	5	4	2,462	143	2,605	60
70	75	47	6,730	300	6	5	3,363	125	4,390	70
				1,880				497		

were : for larch 481, for Scots pine 334, and for spruce 157, making a total of 972. In addition, 128 plots of Japanese larch, Douglas fir, Corsican pine, and other conifers were measured and preliminary tables prepared, but further statistics are required before final yield tables for these exotic species become available.

The larch and spruce woods are arranged into five quality classes

each, and the Scots pine woods into three, according to their mean height at the age of 50 years, as follows :—

Species.	Mean Height.	Quality Class.
Larch and Spruce . . .	80 feet	I.
" " . . .	70 "	II.
" " . . .	60 "	III.
" " . . .	50 "	IV.
" " . . .	40 "	V.
Scots Pine	60 "	I.
" "	50 "	II.
" "	40 "	III.

The results were published in the Forest Commissioners' *Bulletin*, No. 3, of June, 1920. Copies will be found in Appendix V.

It is proposed to use some of these yield tables to illustrate the methods of determining the financial results of forestry in Britain. For that purpose, the volume yield tables have been converted by the author into money yield tables, as given on pages 124—127. For larch, Classes I. to IV. are given, while Class V. has been omitted, as the planting of that class of locality would lead to financial loss, even if the land were given free. For spruce, Classes I., II. and III. (average) are given, and for Scots pine Classes I. and II. (average) for Scotland.

In each case, the columns *b*, *c*, *d* and *e* are taken from the volume yield tables, while columns *f* to *j* give the money values of the final cuttings and the thinnings. Columns *b* and *c* show the class of produce obtained under varying rotations. The prices per cubic foot of final cuttings and of thinnings are approximately the averages of those which prevailed before the War. Present prices are as yet affected by the results of the War, and it is difficult to say what they will be a few years hence.

CHAPTER II.

METHODS OF CALCULATING THE VALUE OF FORESTS.

SECTION I.—VALUATION OF FOREST SOIL.

THE soil can be utilized in two ways :—

Either by using it direct, as for mining, quarrying, construction of buildings, etc.

Or by using it for the production of other goods, such as field or forest crops.

In each of these cases, the soil may have a different value. Forest valuation ascertains the value which the soil has if used for the production of forest crops. For this purpose, it determines the market, cost and expectation values and also the rental of the soil.

1. THE MARKET VALUE OF FOREST SOIL.

By this is understood the value which soil realises in the open market. In most localities a market value of soil has been established. In the majority of cases it represents the value which the soil has for certain purposes, such as agriculture. In the latter case, the market value of good land is generally higher than the forest value, and lower in the case of inferior land.

2. THE COST VALUE OF FOREST SOIL.

By this is understood the sum of all expenses incurred in acquiring the land and rendering it fit for forest culture. These expenses comprise :—

(1.) The price paid for the land.

(2.) The sum paid for the improvement of the land, such as drainage, irrigation works, levelling, fixation, etc.

(3.) The interest accumulated on the outlay under (1) and (2) up to the time when the first forest crop is started, less any income derived from the land during that period.

Example.—A piece of land was bought for £5 per acre, a further sum of £2 per acre was spent on draining the land, and it became fit for planting after three years. At the end of that time a sum of £1 per acre was received as shooting rent and grazing fee. The cost value of the land per acre at the time of planting, allowing 4 per cent. interest, amounted to

$$S_c = (5 + 2) \times 1{\cdot}04^3 - 1 = £6\ 17s.\ 6d.$$

3. The Expectation Value of Forest Soil.

By the expectation value of forest soil is understood the value of all returns expected from the soil in the course of time, less the value of all the expenses which must be incurred to obtain those returns, discounted, in both cases, with compound interest to the time when the first planting or sowing of the land was made ; in other words, the commencement of the first rotation.

For the purpose of obtaining a formula for the soil expectation value, the best method is to take each of successive rotations by itself, and to assume that what happens during the first rotation is repeated during every succeeding rotation. It is convenient to calculate the values of all receipts and expenses, except annually recurring items, during the first rotation for the end of that rotation, such as—

(1.) Cost of formation, c shillings, value in the year $r = c \times 1{\cdot}0p^r$.

(2.) Thinnings in the years, a, b, . . . q, indicated by T_a, T_b, . . . $T_q = T_a \times 1{\cdot}0p^{r-a} + T_b \times 1{\cdot}0p^{r-b} + \ldots + T_q \times 1{\cdot}0p^{r-q}$. Other produce being realised periodically is dealt with in the same way as thinnings. The value of casual items of income or expenditure must be calculated separately and added to or subtracted from the value of S_e as calculated above.

(3.) Final cutting in the year $r = Y_r$. The net amount of these items comes to :—

$$Y_r + T_a \times 1{\cdot}0p^{r-a} + T_b \times 1{\cdot}0p^{r-b} + \ldots + T_q \times 1{\cdot}0p^{r-q} - c \times 1{\cdot}0p^r.$$

This amount, together with the same amount realised at the end of each succeeding rotation, must be discounted to

the commencement of the first rotation, which is done according to Formula VIII., by dividing it by $1{\cdot}0p^r - 1$.

(4.) From the amount so far obtained must be deducted the net amount of the annually occurring receipts and expenses, e, calculated for the commencement of the first rotation. As these expenses have to be met for ever, their present value, according to Formula VII., amounts to $\frac{e}{\cdot 0p}$. Amongst the expenses included in e are the cost of administration, protection, upkeep of roads, and other means of communication, taxes, etc.; amongst the annual receipts appear shooting rents, grazing fees, etc.

The general formula for the soil expectation value, in its simplest shape, runs, therefore, as follows :—

$$\mathbf{S_e} = \frac{\mathbf{Y_r + T_a \times 1{\cdot}0p^{r-a} + T_b \times 1{\cdot}0p^{r-b} + \ldots + T_q \times 1{\cdot}0p^{r-q} - c \times 1{\cdot}0p^r}}{\mathbf{1{\cdot}0p^r - 1}} - \frac{\mathbf{e}}{\mathbf{\cdot 0p}}.$$

Another somewhat more complicated method of calculation is to discount directly with compound interest all items of receipts and costs to the beginning of the first rotation; the difference between the two represents the soil expectation value. It leads to exactly the same formula as that given above.

Example.—An acre of land is to be planted at once with larch. It has been found, after due investigation, that it is capable of yielding returns like those in the money yield table for III. quality of larch given on page 125, and that the desired class of timber can be obtained under a rotation of 60 years. The expenses are expected to be as follows :—

Cost of planting every 60 years = 100 shillings.

Annual expenses less annual income = 6 shillings.

Money for expenses taken out of an investment giving 4 per cent. interest.

The expectation value of the soil will be :—

$$S_e = \frac{2847 + 23 \times 1{\cdot}04^{30} + 117 \times 1{\cdot}04^{20} + 210 \times 1{\cdot}04^{10} - 100 \times 1{\cdot}04^{60}}{1{\cdot}04\cdot^{60} - 1} - \frac{6}{\cdot 04}.$$

By using the Tables in Appendix ~~I~~ III., the above value becomes :—

$$S_e = \Big[2847 + 23 \times 3{\cdot}2434 + 117 \times 2{\cdot}1911 + 210 \times 1{\cdot}4802 - 100 \times 10{\cdot}5196\Big] \times \cdot 105 - \frac{6}{\cdot 04}.$$

$S_e = 105{\cdot}8681$ shillings.

SECTION II.—VALUATION OF THE GROWING STOCK (OR STAND).

The value of the growing stock can be determined as the market, cost, or expectation value. The valuation may refer to a single wood, or to a whole series of age gradations, representing the normal growing stock of a working section or of a whole forest.

1. The Market Value of the Growing Stock of a Single Wood.

By the market value of the growing stock of a wood is understood the price which it would realise if offered to public competition. It may be sold under one of the following conditions :—

(1.) The wood is to be cut down at once. In this case the value is ascertained by determining the volume of the growing stock and multiplying it by the average price of the unit of measurement. It represents the utilization value.

(2.) The growing stock is sold, but allowed to grow on for a number of years. In this case, the purchaser would have to rent the soil for a number of years, and to meet certain other expenses ; in other words, the sale value would be equal to the expectation value to be dealt with below.

The utilization value of very young woods is generally small, so that sales under condition (1.) are rare, until the growing stock has reached, or at any rate approached, ripeness for domestic or industrial purposes. Hence, young woods, if sold at all, are generally disposed of under condition (2.).

2. The Cost Value of the Growing Stock of a Single Wood.

The cost value of the growing stock of a wood now m years old is equal to the value of all costs of production, less the value of all returns which the wood has yielded before the year m, both amounts being calculated for the year m.

Costs of Production.—(*a*) The value of the rent of the soil during m years : $S \times 1{\cdot}0p^m - S = S\ (1{\cdot}0p^m - 1)$.

(*b*) The value in the year m of the cost of formation $= c \times 1{\cdot}0p^m$.

(*c*) The value of the annual expenses during m years (Formula IV.) $\frac{e}{\cdot 0p}(1{\cdot}0p^m - 1) = E(1{\cdot}0p^m - 1)$.

Receipts.—These consist of all previous thinnings and other items of income realised before the year m; they may be represented by T_a, T_b . . . T_l. Their value in the year m is :—

$$T_a \times 1{\cdot}0p^{m-a} + T_b \times 1{\cdot}0p^{m-b} + \ldots + T_l \times 1{\cdot}0p^{m-l}.$$

The general formula for the cost value G_c is, therefore :—

$$\mathbf{{}^mG_c = (S_c + E)\ (1{\cdot}0p^m - 1) + c \times 1{\cdot}0p^m - \Big[T_a \times 1{\cdot}0p^{m-a} + \ldots + T_l\ 1{\cdot}0p^{m-l}\Big]}.$$

Example.—Taking the same data as in the case of the soil expectation value and S, the cost value of the soil = 100 shillings, the cost value of the 45 years old growing stock comes to :—

$$^{45}G_c = (100 + 150)\,(1{\cdot}04^{45} - 1) + 100 \times 1{\cdot}04^{45} - \Big[23 \times 1{\cdot}04^{15} + 117 \times 1{\cdot}04^{5}\Big].$$

$$^{45}G_c = 250 \times 4{\cdot}8412 + 100 \times 5{\cdot}8412 - \Big[23 \times 1{\cdot}8009 + 117 \times 1{\cdot}2167\Big].$$

$^{45}G_c = 1611$ shillings.

3. The Expectation Value of the Growing Stock of a Single Wood.

The expectation value of the growing stock of a wood now m years old is equal to the value, in the year m, of all incomes which may be expected from the wood between the year m and the end of the rotation in the year r, less the value of all expenses which must be incurred during the same period of time.

Using the same data as those given in the case of the valuation of the forest soil, the receipts consist of :—

Thinnings to be realised in the years n, o . . . q, and the final yield in the year r. Their value in the year m amounts to :—

$$\frac{T_n}{1{\cdot}0p^{n-m}} + \frac{T_o}{1{\cdot}0p^{o-m}} + \frac{T_p}{1{\cdot}0p^{p-m}} + \frac{T_q}{1{\cdot}0p^{q-m}} + \frac{Y_r}{1{\cdot}0p^{r-m}}.$$

or, if brought under the same denomination—

$$\frac{T_n\, 1{\cdot}0p^{r-n}}{1{\cdot}0p^{r-m}} + \ldots + \frac{T_q\, 1{\cdot}0p^{r-q}}{1{\cdot}0p^{r-m}} + \frac{Y_r}{1{\cdot}0p^{r-m}}.$$

The expenses consist of :—

(1.) The rent of the soil to be paid from the year m to the year r, the annual amount being $S_e \times {\cdot}0p$. The total amount (Formula VI.) comes to

$$\frac{(S_e \times {\cdot}0p)\,(1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m} \times {\cdot}0p} = \frac{S_e\,(1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m}}.$$

(2.) The annual expenses are (according to Formula VI.) :—

$$\frac{e\,(1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m} \times {\cdot}0p} = \frac{E\,(1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m}}.$$

The formula for the expectation value of the growing stock is :—

$$\mathbf{{}^{m}G_{e}} = \frac{\mathbf{Y_r + T_n \times 1{\cdot}0p^{r-n} + \ldots + T_q \times 1{\cdot}0p^{r-q} - (S_e + E)\ (1{\cdot}0p^{r-m} - 1)}}{\mathbf{1{\cdot}0p^{r-m}}}.$$

Example.—Taking the same data as before, larch III. quality, the expectation value of a 45 years old growing stock is :—

$${}^{45}G_e = \frac{2847 + 210 \times 1{\cdot}04^{10} - (105{\cdot}8681 + 150) \times (1{\cdot}04^{15} - 1)}{1{\cdot}04^{15}} = 1{,}639 \text{ shillings.}$$

The valuation of the growing stock of a whole forest, consisting of a series of woods, is dealt with further on.

SECTION III.—VALUATION OF A WHOLE WOOD (SOIL AND GROWING STOCK).

1. The Cost Value of a Whole Wood.

The cost value of a wood is equal to the cost value of the soil plus that of the growing stock. Let the age be m years :—

$${}^{m}F_c = S + (S + E)\,(1{\cdot}0p^m - 1) + c \times 1{\cdot}0p^m - (T_a \times 1{\cdot}0p^{m-a} + \ldots + T_l \times 1{\cdot}0p^{m-l}),$$

which becomes, after reduction :

$$\mathbf{{}^{m}F_c = (S + E + c) \times 1{\cdot}0p^m - (T_a \times 1{\cdot}0p^{m-a} + \ldots + T_l \times 1{\cdot}0p^{m-l} + E)}.$$

Example.—Placing $m = 45$ years, $r = 60$ years, $p = 4$ per cent., and $S_c = 100$ shillings.

$$^{45}F_c = (\overset{S}{100} + \overset{E}{150} + \overset{c}{100}) \times 5{\cdot}8412 - (23 \times 1{\cdot}8009 + 117 \times 1{\cdot}2167 + 150)$$

$^{45}F_c = 1{,}711$ shillings. The results obtained before were—

$$S_c + {}^mG_c = 100 + 1611 = 1711.$$

2. The Expectation Value of a Whole Wood.

The expectation value of a wood is equal to the expectation value of the soil plus that of the growing stock :—

$$^mF_e = S_e + \frac{Y_r + T_a \times 1{\cdot}0p^{r-n} + \ldots + T_q \times 1{\cdot}0p^{r-q} - (S_e + E)(1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m}},$$

and

$$^mF_e = \frac{S_e + Y_r + T_n \times 1{\cdot}0p^{r-n} + \ldots + T_q \times 1{\cdot}0p^{r-q} - E\,(1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m}}$$

This formula involves two calculations, one of S_e and a second of F_e. They can be combined into one by introducing the expectation value S_e as given on page 131, thus obtaining, after the necessary reductions, the following formula :—

$$\mathbf{^mF_e = \frac{1{\cdot}0p^m\left(Y_r + T_n \times 1{\cdot}0p^{r-n} + \ldots + T_q \times 1{\cdot}0p^{r-q} + \frac{T_a}{1{\cdot}0p^a} + \ldots + \frac{T_1}{1{\cdot}0p^1} - c\right)}{1{\cdot}0p^r - 1} - E.}$$

Example.—Let $m = 45$ years, $r = 60$ years, and $p = 4$ per cent. :—

$$^{45}F_e = \frac{1{\cdot}04^{45}\,(2847 + 210 \times 1{\cdot}4802 + 23 \times {\cdot}3083 + 117 \times {\cdot}2083 - 100)}{1{\cdot}04^{60} - 1} - 150$$

$^{45}F_e = 1{,}745$ shillings.

The results obtained before were : $F_e = S_e + G_e = 106 + 1639 = 1745$. The cost value, $^{45}F_c = 100 + 1611 = 1711$, is smaller than the expectation value, because the soil was obtained for less than its expectation value.

CHAPTER III.

THE FINANCIAL RESULTS OF FORESTRY.

The financial results of forestry can be determined in one of the following two ways :—

(1.) Determination of the profit, that is to say, the surplus of receipts over costs of production, allowing compound interest at a certain rate on both.

(2.) Determination of the rate of interest yielded by the capital invested in forestry, called the "forest per cent."

SECTION I.—CALCULATION FOR THE INTERMITTENT WORKING.

1. Calculation of the Profit of Forestry.

In the case of a single wood of approximately even age, the returns and costs do not occur at the same time, but at intervals of various length ; hence, they must be calculated for one and the same time. In the first place, that time shall be the commencement of the rotation, when the area is about to be planted or sown for the production of a new forest crop ; secondly, the profit in the case of a wood now *m* years old.

a. Calculation for a Blank Area.

In addition to the signs used above, let "p" be the per cent. at which money can be made available for investment in forestry, and at which money taken out of the forest can be invested with equal security ; or the minimum per cent. at which the proprietor is willing to invest money in forestry. The profit is then represented by :—

Profit = Receipts — Costs, calculated for the year O.

$$\text{Profit} = \frac{Y_r + T_a \times 1{\cdot}0p^{r-a} + \ldots + T_q \times 1{\cdot}0p^{r-q}}{1{\cdot}0p^r - 1} - \\ - \left(S^c + E + \frac{c \times 1{\cdot}0p^r}{1{\cdot}0p^r - 1}\right).$$

This formula may also be written as follows :—

$$\text{Profit} = \left(\frac{Y_r + T_a \times 1{\cdot}0p^{r-a} + \ldots + T_q \times 1{\cdot}0p^{r-q} - c \times 1{\cdot}0p^r}{1{\cdot}0p^r - 1.} - E\right) - S_c.$$

As the part in brackets represents the expectation value of the soil, the formula is reduced to :—

$$\text{Profit} = S_e - S_c.$$

In words : the profit in the case of a blank area, after allowing p per cent. interest on all receipts and costs, is equal to the difference between the expectation and the cost values of the soil, hence :—

(1.) The greater the difference the higher will be the profit over and above p per cent. ; in other words, the management must aim at the highest possible expectation value of the soil and the lowest cost of production admissible with due consideration for efficiency.

(2.) If the cost value of the soil is equal to the expectation value, the profit is nil, and the capital invested in the forest gives exactly p per cent. If the cost value is greater than the expectation value, a financial loss is incurred, and it would be more profitable to take the capital out of the forest and invest it otherwise, as long as in this way p per cent. can be obtained with equal security.

b. Calculation for a Wood m *years old.*

Analogous to that employed for a blank area, the profit of a whole wood now m years old is expressed by :—

$$\text{Profit} = {}^mF_e - {}^mF_c.$$

The formula for the expectation value will be found on page 135. The cost value may be the price paid on purchase, or it may be determined as given on page 134. If the returns and costs are the same in either case, the following equation should hold good :—

$$\text{The profit} = {}^mF_e - {}^mF_c = (S_e - S_c) \times 1{\cdot}0p^m.$$

The conclusions drawn above as regards the profit of a blank area also hold good as regards that obtained from a forest *m* years old.

Example.—It has been found above that $S_e - S_c = 105{\cdot}8681 - 100 = 5{\cdot}8681$ shillings per acre.

Also: ${}^{45}F_e - {}^{45}F_c = 1744 - 1711 = 34$, and
$(S_e - S_c) \times 1{\cdot}04^{45} = 5{\cdot}8681 \times 5{\cdot}8412 = 34$ shillings per acre.

2. Determination of the Rate of Interest yielded by the Capital Invested in Forestry.

The general aspect of the matter has been considered in Chapter I. (page 115), where it has been stated that the per cent. applicable to the forest industry may be ascertained in one of the following three ways :—

(1.) To accept the per cent. used in the agricultural industry, or
(2.) To accept the per cent. yielded by Government Consols, or
(3.) To determine the forest per cent. from the net receipts and capital of forests.

The first and second methods give results which are more or less estimates, even if modified according to local conditions ; hence, the scientific forester must aim at more satisfactory results under the third method.

In dealing with the matter, a distinction must be made between the intermittent working and the strictly annual working of a forest. The determination of the per cent. under the latter method is comparatively easy, but much more complicated under the former. In that case the interest changes from year to year, because the capital and the increment change with advancing age of the wood. A further distinction is necessary between the current annual and the mean (or average) annual forest per cent.

a. The Current Annual Forest Per Cent.

As already indicated, the per cent. yielded by an ordinary capital is expressed by the formula—

$$\text{Per cent. } p = \frac{\text{Annual interest}}{\text{Producing capital}} \times 100 = \frac{I}{C} \times 100.$$

This formula is used in the case of forestry by introducing the proper values for I and C. These are the net annual value increment of a wood for I and the cost value of the forest for C at the commencement of the year in question. Let the utilization value of the growing stock be $= {}^{m}G_y$ at the beginning of the year and $= {}^{m+1}G_y$ at the end of the year, then ${}^{m+1}G_y - {}^{m}G_y$ represents the increase in the value which has been produced during the year. Deducting from this amount the net annual costs e, the net increase in value is equal to ${}^{m+1}G_y - {}^{m}G_y - e$, and the formula for the current annual forest per cent. is :—

$$\text{Current } p_f = \left(\frac{{}^{m+1}G_y - {}^{m}G_y - e}{{}^{m}F}\right) \times 100 = \left(\frac{{}^{m+1}G_y - {}^{m}G_y - e}{S + {}^{m}G}\right) \times 100.$$

Against the use of this formula is the difficulty of ascertaining the value increment of the growing stock during one year. The amount is small compared with the limit of error involved in the measurement of a growing wood ; moreover, annual increments vary from year to year. Hence, it is necessary to determine the increment during a number of years, say 5 or 10 or n years. During the n years the annual value increment of the growing stock, as well as the producing capital, change from year to year under the influence of growth, on the one hand, and the effect of expenses, on the other hand ; in other words, the value of the forest in the year $m + n$ is produced by the value of the forest in the year m working with compound interest at a certain rate of interest which may be called p_f, the forest per cent., according to the formula :—

$${}^{m+n}F = {}^{m}F \times 1{\cdot}0p_f^{\,n}.$$

Out of this is obtained—

$$1{\cdot}0p_f^{\,n} = \frac{{}^{m+n}F}{{}^{m}F}, \text{ and } 1{\cdot}0p_f = \sqrt[n]{\frac{{}^{m+n}F}{{}^{m}F}}, \text{ and } {\cdot}0p_f = \sqrt[n]{\frac{{}^{m+n}F}{{}^{m}F}} - 1,$$

$$p_f = 100 \times \sqrt[n]{\frac{{}^{m+n}F}{{}^{m}F}} - 100, \text{ or, in logarithms :—}$$

$$\log.\ (100 + p_f) = 2 + \frac{\log.\ {}^{m+n}F - \log.\ {}^{m}F}{n}.$$

This formula is known as Pressler's "Weiserprozent" formula, which the author translated, many years ago, as the "Indicating Per Cent." If calculated for successive periods, it indicates whether a wood is financially ripe or not. As long as the indicating per cent. is larger than the per cent. p at which money can be otherwise invested with equal security, or at which money can be obtained for investment in forestry, the wood is financially not ripe; when the indicating per cent. has sunk and become equal to the general per cent. p, the wood is financially ripe. If the wood is kept growing after that age, the indicating per cent. is smaller than the general per cent. p, and the wood is passed financial ripeness, unless an unexpected rise in the price per unit of measurement occurs.

The use of the above formula is complicated, as the value of F has to be calculated in the first place. Hence, in the case of forests under fairly regular treatment, foresters substitute the utilization value (G_y) for G, thus obtaining results sufficiently accurate for practical purposes. The formula then becomes :—

$$\text{Current } p_f = 100 \times \left[\sqrt[n]{\frac{{}^{m+n}G_y + S_c}{{}^{m}G_y + S_c}} - 1 \right], \text{ and} \quad . \quad . \quad . \quad (1)$$

$$\log. (100 + p_f) = 2 + \frac{\log. ({}^{m+n}G_y + S_c) - \log. ({}^{m}G_y + S_c)}{n} \quad . \quad (1)$$

In order to avoid the use of logarithms, various formulas have been evolved. Pressler obtained such a formula by assuming that the value increment during the n years is produced in annually equal quantities, and that the producing capital is equal to the arithmetical mean of the growing stocks present at m and $m + n$ years. He thus obtains the equation—

$$\overset{\text{Capital}}{\frac{({}^{m+n}G_y + {}^{m}G_y)}{2}} : \overset{\text{Annual increment}}{\frac{({}^{m+n}G_y - {}^{m}G_y)}{n}} = 100 : p_f$$

and

$$\text{Current } p_f = \frac{{}^{m+n}G_y - {}^{m}G_y}{{}^{m+n}G_y + {}^{m}G_y} \times \frac{200}{n} \quad . \quad . \quad . \quad (2)$$

The formula was obtained by experimental measurements.

Examples.—Given the data in the yield table for larch III. quality, and $n = 10$, the following result is obtained for formula (1) above :—

Period 40–50 :

$$\text{Log.}\,(100 + p_f) = 2 + \frac{\log.\,(2150 + 100) - \log.\,(1336 + 100)}{10};\ p_f = 4{\cdot}59.$$

Period 50–60 : $p_f = 3{\cdot}75$. Period 60–70 : $p_f = 3{\cdot}67$.

According to Formula (2) the results are :—

Period 40–50 :

$$\text{Current } p_f = \frac{2150 - 1336}{2150 + 1336} \times \frac{200}{10} = 4{\cdot}67 \text{ per cent.}$$

Similarly for Period 50–60, $p_f = 3{\cdot}79$, and for 60–70, $p_f = 3{\cdot}68$ per cent.

COMPARISON OF THE RESULTS.

Period.	By Formula I.	By Formula II.	Difference.
40—50	4·59	4·67	+ 0·08
50—60	3·75	3·79	+ 0·04
60—70	3·67	3·68	+ 0·01
		Average	.. + 0·04

Formula (2) gives slightly higher values, but the difference is so small that it may well be neglected.

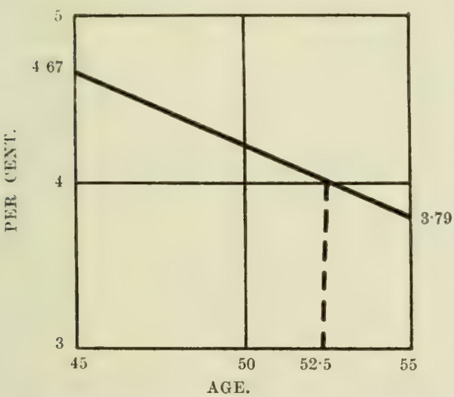


Fig. 39.—Showing Age of Financial Ripeness.

Assuming in the above example that the general per cent. is equal to 4 per cent., it will be observed that the indicating per cent. during the period 40—50 is greater than 4 per cent. and smaller during the period 50—60 ; hence, the two must be equal at some time between 40 and 60. To ascertain the exact year, the data may be plotted as in Fig. 39, which shows that, according to the data of Formula (2), the indicating per cent. is equal to 4 per cent. in the year 52—53.

b. The Mean Annual Forest Per Cent.

The determination of the mean annual forest per cent. has, in the past, puzzled foresters very considerably. Various methods of determination have been evolved, but none were satisfactory. Only one of these will be mentioned here, because it was given in previous editions of this volume for want of a more satisfactory method at the time. It was based on utilizing the general formula $p = \frac{I}{C} \times 100$, and introducing into it the values for I and C appertaining to forestry. The annual net income calculated for the commencement of the rotation is expressed by $S_e \times \cdot 0p$ and the producing capital by S_c, so that the formula becomes—

$$\text{mean } p_f = \frac{S_e \times \cdot 0p}{S_c} \times 100 = \frac{S_e}{S_c} \times p,$$

p being the per cent. fixed by the proprietor, or the forester. It is clear that the equation holds good only when p happens to be = mean p_f. For all other periods of the rotation, the formula gives only approximately correct results, the difference depending to a great extent on the accuracy with which p has been estimated, and on the difference between the year for which the calculation is made and the year when $p = p_f$.

The author kept the matter in mind, and when preparing his "Forestry in the United Kingdom," he evolved a new method, described at pages 41 to 51 of that pamphlet, published in 1904. He brought the market value of the soil into direct relation with the expectation value of the soil by placing the one equal to the other, thus obtaining the formula—

$$S_c = \frac{Y_r + T_a \times 1{\cdot}0p^{r-a} + \ldots + T_q \times 1{\cdot}0p^{r-q} - c \times 1{\cdot}0p^r}{1{\cdot}0p^r - 1} - \frac{e}{\cdot 0p}.$$

In this equation p represents the mean forest per cent. corresponding to a given cost value of the soil. The lower the latter is, the higher will be the mean forest per cent., and *vice versâ*. The difficulty was, however, that the equation is not directly soluble, and the author proceeded, therefore, to make trial calculations. He calculated the soil expectation values with various per cents.,

and plotted the results opposite the soil cost values, both on the same scale. He thus obtained a graph from which the mean forest per cent. could be read off for any soil cost value. The point, where a line drawn horizontally from any soil cost value meets the graph of expectation values, gives the mean forest per cent. for that soil value.

When writing the above-mentioned pamphlet, the object was to determine the mean forest per cent. for various species managed for the production of fair-sized saw timber, and the calculations were made for :—

Larch	managed	under a	rotation of	70	years.
Ash	,,	,,	,,	70	,,
Scots pine	,,	,,	,,	80	,,
Spruce	,,	,,	,,	90	,,
Beech	,,	,,	,,	120	,,
Oak	,,	,,	,,	130	,,

The calculations were based upon yield tables modified to meet English conditions. By way of illustration, the author gave the calculations for larch. The returns for that species were given as follows :—

A thinning in the year	20,	value	=	10	shillings
,, ,, ,,	30	,,	=	76	,,
,, ,, ,,	40	,,	=	220	,,
,, ,, ,,	50	,,	=	270	,,
,, ,, ,,	60	,,	=	300	,,
A final yield in the year	70,	value	=	3,900	shillings.

The cost of planting was given as £4 10*s.* 0*d.* per acre ; the net amount of the annual expenses for administration, etc., at 4 shillings per acre. The following soil expectation values were obtained :—

					£	*s.*	*d.*
Calculated with	$2\frac{1}{2}$	per cent.	= 910	shillings	= 45	10	0
,, ,,	3	,,	= 576	,,	= 28	16	0
,, ,,	$3\frac{1}{2}$	,,	= 364	,,	= 18	4	0
,, ,,	4	,,	= 221	,,	= 11	1	0
,, ,,	$4\frac{1}{2}$	,,	= 123	,,	= 6	3	0
,, ,,	5	,,	= 55	,,	= 2	15	0

These data were plotted with the per cents. as abscissæ and the soil values as ordinates, giving the following graph for a rotation of 70 years.

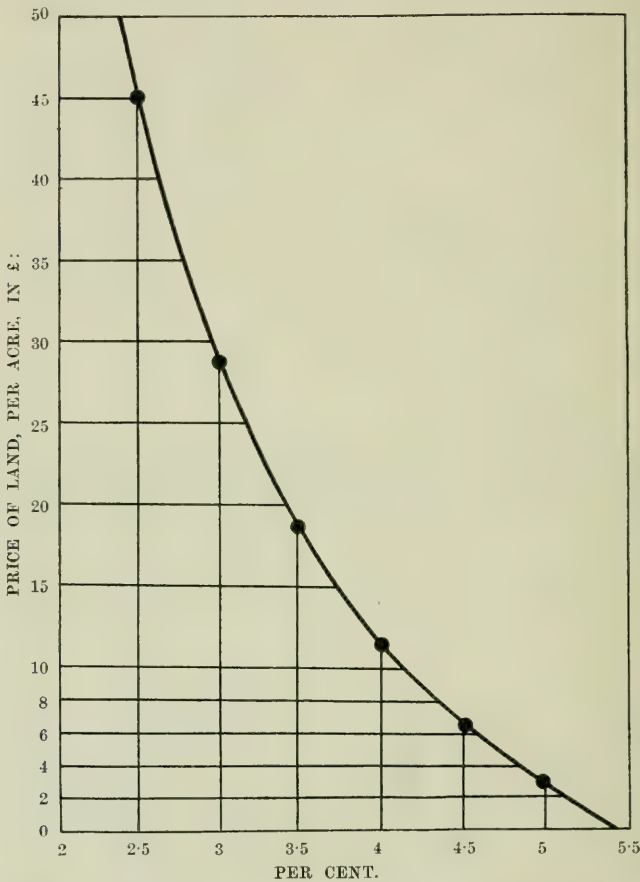


Fig. 40.—Schlich's Graph indicating the Mean Forest Per Cent. (From Schlich's "Forestry in the United Kingdom," 1904.)

As a separate graph is required for each rotation, a second example was given for a rotation of 40 years, suitable for the production of pit timber or other material of a similar size. Thus, the author of this book initiated in 1904 the method of determining the mean annual forest per cent. by means of a graph, which was obtained by plotting a series of trial calculations made with

Indicator Graph for Larch III. Quality.

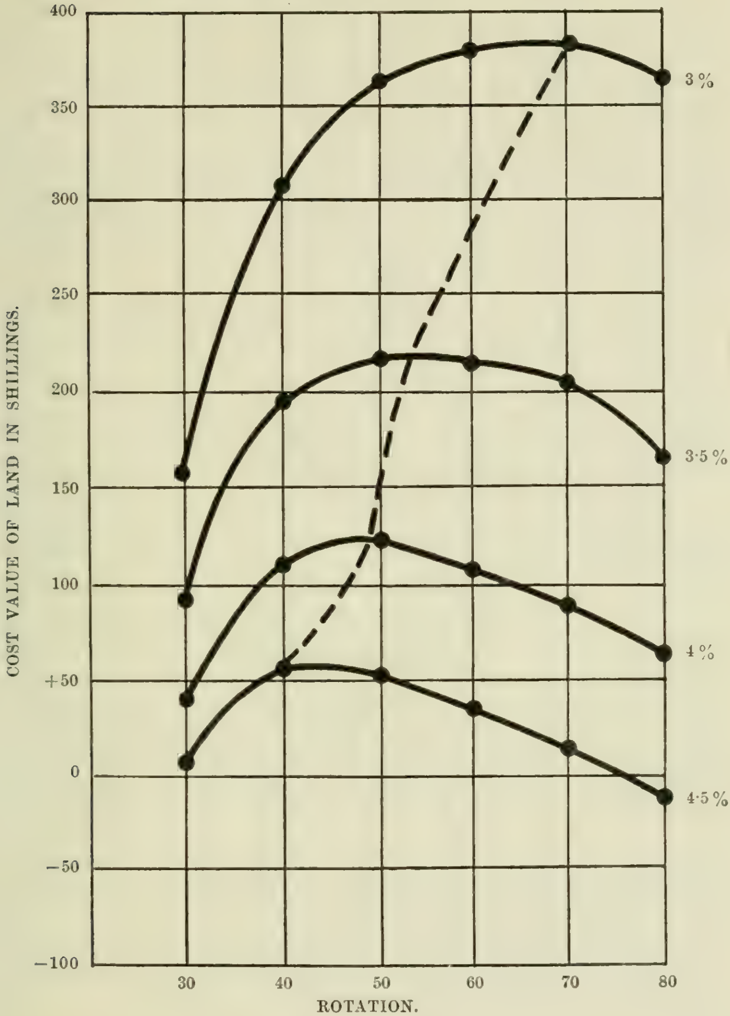


Fig. 41.

various per cents. It will be observed that Fig. 40 indicates the mean annual forest per cent. for a rotation of 70 years as equal to 4·7 per cent., if the cost value of the soil amounts to £5.*

* By an oversight, due to the author's illness from July, 1904, to October, 1905, the new method was not incorporated in Volume III.

Subsequently, in 1919, Mr. W. E. Hiley, Research Officer at the School of Forestry, Oxford, calculated the expectation values for larch for various rotations, and constructed with them a graph which gives the mean forest per cent. for any rotation and also the year in which the forest per cent. reaches its maximum (though this is already given by the expectation values). Hiley called it the "indicator graph" and published it in the July number, 1919, of the *Quarterly Journal of Forestry*. The appended Fig. 41, constructed with the data for larch III. quality, page 125, will explain the indicator graph.

It will be observed that Hiley's graph is based on the same principle as Schlich's graph.* The former involves, however, much more work than the latter, which is a consideration, as every change of the quality class requires a separate graph. In cases where the object is to give a general idea of the financial aspect of forestry over a considerable stretch of country, Hiley's graph is in its place, but in the majority of practical cases the calculation for one rotation according to Schlich's graph is quite sufficient especially when the proprietor, or forester, decides to grow a definite class of produce for which a definite rotation is indicated. The Sub-Committee on Forestry, 1915, when dealing with the financial aspect of forestry in Great Britain and Ireland, assumed a suitable rotation for each species to be cultivated, and determined the mean forest per cent. for each species by Schlich's method of graphs (see pages 65 to 68 of the Report, or pages 103 to 108 of Volume I. of Schlich's "Manual of Forestry," 4th Edition).

SECTION II.—THE FINANCIAL RESULTS OF A FOREST WORKED FOR A SUSTAINED ANNUAL YIELD.

A distinction must be made between a forest which is in the "normal state," and one which consists of a number of woods of various ages and areas deviating from the normal state.

1. Description and Value of the Normal Forest.

If a forest is so managed that it yields annually, or periodically, an equal return, it must contain a series of woods of equal yield capacity ranging in age from 1 to r years. If the difference in

* Apparently Hiley had not seen my "Forestry in the United Kingdom" when he conceived the idea of constructing his graph, though he had seen it before he published his graph.

age between every two successive woods is 1 year, the whole is called a "normal series of age gradations"; if the difference amounts to several years—say, 5, 10 or more—it is called a "normal series of age classes." In the former case, the oldest age gradation will be cut year after year; in the latter case, the oldest age class will be cut in the course of a number of years in such proportion that an annually equal return is obtained.

Taking the case of a normal series of age gradations running from 1 to r years, there will remain after the annual cutting, say, in winter, a series of woods running from 0 to $r - 1$ years, and this is called the "normal growing stock." It is brought up to the full series during the next growing season in spring and summer, and again reduced to the normal growing stock during the next winter; it is the minimum growing stock present in the normal forest. Its value is obtained by adding up, either the expectation values, or the cost values of all the age gradations from 0 to $r - 1$ years old.

The expectation values of the several age gradations, according to the formula on page 135, are as follows :—

$$^{r-1}G_e = \frac{Y_r - (S + E)\,(1{\cdot}0p^1 - 1)}{1{\cdot}0p^1}$$

$$^{r-2}G_e = \frac{Y_r - (S + E)\,(1{\cdot}0p^2 - 1)}{1{\cdot}0p^2}$$

$$\vdots$$

$$^{q}G_e = \frac{Y_r - (S + E)\,(1{\cdot}0p^{r-q} - 1)}{1{\cdot}0p^{r-q}}$$

$$^{q-1}G_e = \frac{Y_r + T_q \times 1{\cdot}0p^{r-q} - (S + E)\,(1{\cdot}0p^{r-(q-1)} - 1)}{1{\cdot}0p^{r-(q-1)}}$$

$$\vdots$$

$$^{0}G_e = \frac{Y_r + T_q \times 1{\cdot}0p^{r-q} - (S + E)\,(1{\cdot}0p^{r} - 1)}{1{\cdot}0p^{r}}.$$

By introducing the other thinnings in the years $a, b, \ldots p$ and adding up all the items, the following formula is obtained :—

$$^{normal}G_e = \frac{\begin{array}{c}(Y_r + S + E)\,(1{\cdot}0p^r - 1) + T_a \times \\ 1{\cdot}0p^{r-a} \times (1{\cdot}0p^a - 1) + \ldots + \\ T_q \times 1{\cdot}0p^{r-q} \times (1{\cdot}0p^q - 1)\end{array}}{1{\cdot}0p^r \times {\cdot}0p} - r\,(S + E).$$

By introducing the soil expectation value for S into the formula, the latter reduces to :—

$$^{normal}G_e = \frac{Y_r + T_a + T_b + \ldots + T_q - c}{\cdot 0p} - r\,(S_e + E),$$

or, as
$$E = \frac{e}{\cdot 0p},$$

$$^{normal}G_e = \frac{Y_r + T_a + \ldots + T_q - (c + r \times e)}{\cdot 0p} - r \times S_e.$$

The cost values of the several age gradations, according to the formula on page 134, are as follows :—

$$^{o}G_c = (S + E)\,(1{\cdot}0p^o - 1) + c \times 1{\cdot}0p^o$$

$$^{1}G_c = (S + E)\,(1{\cdot}0p^1 - 1) + c \times 1{\cdot}0p^1$$
$$\vdots$$
$$^{a}G_c = (S + E)\,(1{\cdot}0p^a - 1) + c \times 1{\cdot}0p^a - T_a$$

$$^{a+1}G_c = (S + E)\,(1{\cdot}0p^{a+1} - 1) + c \times 1{\cdot}0p^{a+1} - T_a \times 1{\cdot}0p$$
$$\vdots$$
$$^{r-1}G_c = (S + E)\,(1{\cdot}0p^{r-1} - 1) + c \times 1{\cdot}0p^{r-1} - T_a \times 1{\cdot}0p^{r-a-1} \ldots - T_q \times 1{\cdot}0p^{r-q-1}.$$

The sum of these equations comes to :—

$$^{normal}G_c = \frac{(S_c + E + c)\,(1{\cdot}0p^r - 1) - [T_a\,(1{\cdot}0p^{r-a} - 1) + \ldots + T_q\,(10p^{r-q} - 1)]}{\cdot 0p} - r\,(S_c + E).$$

By introducing the soil expectation value for S_c, this expression becomes the same as that for the expectation value of the growing stock, namely :—

$$^{normal}G_c = {}^{normal}G_e = \frac{Y_r + T_a + \ldots + T_q - (c + r \times e)}{\cdot 0p} - r \times S_e.$$

By adding the value of the soil, $r \times S_e$, to the normal growing stock, the value of the normal forest is obtained :—

$$_{normal}F_e = \frac{Y_r + T_a + \ldots + T_q - (c + r \times e)}{\cdot 0p}.$$

If, on the other hand, the soil cost value, S_c, is introduced in the above formula, and it differs from S_e, then the value of the normal F_c differs from the normal F_e.

The value of the normal F_e can also be obtained by capitalising the net annual return, $Y_r + T_a + \ldots + T_q - (c + r \times e)$. This is done either by multiplying it by a certain number of years' purchase or by dividing it by $\cdot 0p$. If, in that case, p is equal to the mean annual forest per cent., the formula represents the expectation value of the normal forest; if p is arbitrarily fixed by the proprietor at the rate which he paid for the money invested in the forest, the formula gives the cost value of the forest.

Examples.—Taking the date a for larch III. quality, the mean annual forest per cent. (as calculated by the graphic method) at 4 per cent., S_c as 100 shillings and S_e as 105·8681 (as ascertained on page 131), the following results are obtained for a rotation of 60 years :—

$$_{normal}F_e = \frac{2847 + 23 + 117 + 210 - (100 + 60 \times 6)}{\cdot 04} = 68{,}425 \text{ shillings}$$

$$_{normal}F_c = G_c + S_c : (S_c = 100 \text{ shillings}).$$

$$_{normal}G_c = \frac{\begin{array}{c}(100 + 150 + 100)(1{\cdot}04^{60} - 1) - \\ {[23\,(1{\cdot}04^{30} - 1) + 117\,(1{\cdot}04^{20} - 1) +} \\ 210\,(1{\cdot}04^{10} - 1)]\end{array}}{\cdot 04} - 60\,(100 + 150).$$

$$_{normal}G_c = \frac{\begin{array}{c}350 \times 9{\cdot}5196 - (23 \times 2{\cdot}2434 + 117 \times 1{\cdot}1911 + \\ 210 \times {\cdot}4082)\end{array}}{\cdot 04} - 60 \times 250.$$

$$G_c = 61{,}001 \text{ and}$$

$$_{normal}F_c = 61{\cdot}001 + 6{,}000 = 67{,}001.$$

The difference $F_e - F_c = 1{,}424$ shillings is due to $S_c < S_e$.

2. Calculation of the Profit for the Sustained Annual Working.

In this case, the returns and costs occur regularly every year, and the annual profit is represented by their difference :—

$$\text{Annual profit} = (Y_r + T_a + \ldots + T_q - c - r \times e) - (r \times S_c + {}^{normal}G_c) \times \cdot 0p.$$

As this profit occurs every year indefinitely, it can be capitalised by dividing each side of the equation by $\cdot 0p$, thus obtaining the total profit as :—

$$\frac{\text{Annual profit}}{\cdot 0p} = \text{total profit}$$

$$= \frac{Y_r + T_a + \ldots + T_q - c - r \times e}{\cdot 0p} - (r \times S_c + {}^{normal}G_c).$$

The first part on the right side of this equation represents the expectation value of the normal forest and the second part its cost value, so that the total profit of a normal series of age gradations is represented by :—

Total profit $= {}^{normal}F_e - {}^{normal}F_c$; in the above example $= 1{,}424$ shillings.

The conclusions drawn on page 137, as regards the intermittent working also hold good in the case of the sustained annual working.

The calculation of the profit over and above the realisation of a fixed rate of interest on the invested capital is adopted in cases where the proprietor insists on the realisation of a minimum rate. Such profit, if positive, represents, in reality, an addition to the previously fixed rate of interest, or, if negative, a reduction of it; hence, a more satisfactory method is to determine the mean annual forest per cent., a matter dealt with below.

3. Calculation of the Interest under the Sustained Annual Working.

Under the annual working with equal annual increment, yield and costs, the current annual forest per cent. is equal to the mean

annual forest per cent. In this case, the annual net return of r units of area amounts to $Y_r + T_a + \ldots + T_q - c - r \times e$, while the producing capital is represented by the cost value of the forest, giving the formula :—

$$ {}^{mean}p_f = \frac{Y_r + T_a + \ldots + T_q - c - r \times e}{F_c} \times 100. $$

In cases where the value of F_c cannot be ascertained, the market value of F should be substituted for F_c (see page 129, above).

Example.—An area of 60 acres, stocked with a series of age gradations of larch running from 1 to 60 years of age, was bought for £3,250 = 65,000 shillings. On examination it was found that the 50 years old gradation showed an average height of 60 feet, and, as the conditions were of a uniform character throughout, the wood was placed in the III. quality class. *Query :* What interest is the purchaser likely to get from the investment ? The reply, based upon the data in the money yield table for larch, III. quality, on page 125, would be :—

$$ {}^{mean}p_f = \frac{2847 + 23 + 117 + 210 - 100 - 60 \times 6}{65000} \times 100 = 4{\cdot}2 \text{ per cent.} $$

In this example the forest has been bought for £3,250, which would yield an annual interest of 4·2 per cent. If the forest had been obtained for less than £3,250, whether bought or grown, it would give more than 4·2 per cent. and *vice versâ.*

In the above calculations it was assumed that the forest is in the full normal state. In the majority of cases, however, the forest is more or less abnormal, and the forester has the task of leading it over into the normal state, and also of securing an approximately equal annual return. The procedure had better be given in an example :—

Example.—Given a forest of 60 acres stocked with larch of various ages and qualities, which the proprietor desires to work for a sustained annual yield and to convert into a series of 60 normal age gradations in the course of 60 years. The forest has been established during the preceding 60 years with money which yielded on an average 4 per cent. interest, and, before proceeding with the conversion, the proprietor wishes to know what per cent. the invested capital is likely to give him during the conversion period of 60 years.

The forest is situated on an easterly somewhat undulating slope, and the soil and growing stock differ from III. to I. quality. They are best in the

lower parts and only moderate on the elevated parts. An examination shows that the forest consists of the following four lots :—

Compartment.	Area, Acres.	Cost value of Soil per acre.	Average Age of wood.	Quality Class.
		£		
1	7	5	60	III.
2	13	5	45	III.
3	25	10	25	II.
4	15	15	10	I.
	60			

It is assumed that the cost of planting came to £5 per acre and the annual expenses to 6 shillings per acre. The returns must be estimated locally, but for the present purpose they are expected to be those given in the money yield tables for larch on pages 124–5.

The percentage to be obtained during the transition period is determined by the formula :—

$$_{mean}P_f = \frac{\text{Annual Net Income}}{\text{Cost Value of the Forest}} \times 100.$$

Calculation of the Cost Value of the Forest.
(See page 134 for formula.)

$$Comp.1: F_c = [(100 + 150 + 100) \times 1{\cdot}0p^{60} - (23 \times 1{\cdot}0p^{30} + 117 \times 1{\cdot}0p^{20} + 210 \times 1{\cdot}0p^{10} + 150)] \times 7 = 20{,}230 \text{ shillings.}$$

$$Comp.2: F_c = [350 \times 1{\cdot}0p^{45} - (23 \times 1{\cdot}0p^{15} + 117 \times 1{\cdot}0p^{5} + 150)] \times 13 = 22{,}238.$$

$$Comp.3: F_c = [450 \times 1{\cdot}0p^{25} - (20 \times 1{\cdot}0p^{5} + 150)] \times 25 = 25{,}632 \text{ shillings.}$$

$$Comp.4: F_c = [550 \times 1{\cdot}0p^{10} - 150] \times 15 = 9{,}962 \text{ shillings.}$$

Cost Value of the whole Forest = 78,062 shillings = £3,903 2*s.* 0*d.*

Calculation of the Net Income.—The forest will be cut over once in the course of 60 years, and the cuttings during that period will be :—

FINAL YIELDS.

Comp.	Area.	Quality.	Present Age. Years.	Age when Cut. Years.	Yield. Shillings.
1	7	III.	60	60—66	22,071
2	3	III.	45	52—54	6,636
2	10	III.	45	55—64	28,470
3	10	II.	25	45—54	30,430
3	10	II.	25	55—64	38,850
3	5	II.	25	65—69	17,920
4	5	I.	10	55—59	22,335
4	10	I.	10	60—70	60,375
Total ..	60				227,087

Thinnings.—During one rotation of 60 years, thinnings, up to and including that to be made in the year 50, are obtained in each compartment. They may be estimated at the following amounts, according to the data given in the yield tables :—

In the III. quality area of 20 acres × 350 per acre =	7,000	shillings.
In the II. quality area of 25 acres × 565 per acre =	14,125	,,
In the I. quality area of 15 acres × 695 per acre =	10,425	,,
Total of Thinnings	31,550	,,
Grand total of all cuttings . .	258,637	,,
Average Annual Cutting . . .	4,311	,,
From this amount must be deducted the annual costs, consisting of the cost of planting 1 acre, $c = 100$ shillings and the cost of administration, etc., $60 \times 6 = 360$ shillings =	460	,,
Annual Net Return	3,851	shillings.

By introducing the values of the capital and of the mean annual net return into the above formula the mean annual forest per cent. is obtained as :—

$$^{mean}p_f = \frac{3{,}851}{78{,}062} \times 100 = 4{\cdot}9 \text{ per cent.}$$

The actual per cent. under the above given arrangement of cutting will be somewhat less than 4·9 per cent. during the first part of the rotation and more than 4·9 per cent. during the second part of the rotation, but, by slightly altering the annual coupes, the cuttings can be so regulated that wood to the value of 4,311 shillings is cut every year throughout the rotation, giving approximately 4·9 per cent. annually from the beginning of the rotation to its end.

SECTION III.—NOTES ON THE FINANCIAL ASPECT OF FORESTRY.

The forecast of financial results of forestry depends on an estimate of future returns and expenses based upon past experience ; hence, they are to some extent problematic. The degree of uncertainty depends on the intensity of management. It is considerable in the case of irregularly stocked and unsystematically managed forests ; it is small in the case of forests which have been intelligently managed for some time, and for which accurate data have been kept setting forth past receipts and expenses. Such forests exist in several European countries, where future returns are estimated with marvellous accuracy, with the assistance of accurate yield tables for different species

and qualities of locality. Fortunately, a beginning has now been made to supply such tables based upon measurements made in Great Britain and Ireland, and when sufficient progress has been made in that direction, the reproach that British forestry is comparable to "gambling in futures" will be, to a considerable extent, a matter of the past.

Of the two methods of determining the financial results of forestry, by the profit and the mean forest per cent., the former is perhaps less laborious than the latter. It is adopted in cases where the proprietor requires a fixed minimum per cent., without which he is not willing to embark on forestry. The method of the mean annual forest per cent., on the other hand, converts a profit into an addition to the fixed per cent., and a loss into a reduction of it; in other words, it gives the full per cent. which may be expected under a given set of conditions, and it is applicable to all cases.

The mean annual forest per cent. depends on a great variety of conditions, some of which have already been indicated, but it may be useful to refer to them again :—

(1.) The rate per cent., being calculated from the soil expectation values, has a most powerful effect upon the financial results. A high rate gives a low expectation value, and *vice versâ*. The increase, or decrease, is, however, not exactly in inverse proportion to the rate of interest. Again, under a low rate of interest the expectation value culminates later than under a high rate. The expectation values for larch III. quality, are as follows :—

Rotation.	Soil Expectation Values.			
	3 per cent.	3½ per cent.	4 per cent.	4½ per cent.
30	157	90	41	5
40	312	197	115	**55**
50	365	**216**	**122**	52
60	374	214	106	31
70	**385**	209	92	+10
80	364	183	66	−12

The expectation value for a rotation of 80 years, for instance, falls from 364 shillings, calculated with 3 per

cent., to − 12 calculated with 4½ per cent. It may be added that the values calculated with 5 per cent. are all negative, showing that larch grown on a locality of III. quality does not give 5 per cent., even if the soil is given free. The above data further show that the maximum soil expectation value is obtained at the following ages :—

Calculated	with	3	per cent.,	at the age	of	70	years.
,,	,,	3½	,,	,,	,,	55	,,
,,	,,	4	,,	,,	,,	50	,,
,,	,,	4½	,,	,,	,,	40	,,

(2.) The culmination of the expectation values, and consequently of the mean forest per cent., occurs earlier in the case of the better quality classes than in that of the lower classes. The appended statement of mean forest per cents. illustrates this. Taking the mean per cents. of larch grown on land the market value of which is £5 per acre, the culminating ages are : I. quality at 30 years ; II. quality at 40 years ; III. quality at 50 years ; IV. quality at 70 years. In the case of Scots pine : I. quality at 60 years ; II. quality at 70 years. The per cents. for spruce show smaller differences : I. quality at 60 years ; II. quality at 60 years ; III. quality at 65 years. The tables at present available for spruce up to 70 years are based on a somewhat limited number of measurements, and they are liable to alteration on further investigation.

(3.) The appended table shows that the mean per cent. of larch IV. quality is so small that it is more profitable to grow either spruce or Scots pine on such localities. Even larch III. quality give lower results than spruce I. quality for rotations above 40 years. The Forestry Commissioners, in their Bulletin No. 3, advise not to plant larch on localities below III. quality, that is to say, on localities where it does not reach a mean height of 55 feet in 50 years.

Table of Mean Annual Forest Per Cents., according to the Cost Value of the Soil and the Quality Class.

Rotation.	I. Quality.				II. Quality.				III. Quality. Average.			IV. Quality.
	Cost, or Market, Value of the Soil. £:											
	5	10	15	20	5	10	15	20	5	10	15	5
						Larch.						
20	6·3	5·1	4·3	3·8	3·6	2·9	..	..	..	..	..	..
30	**6·7**	5·7	5·0	4·6	5·6	4·7	4·0	3·6	3·4	2·9	..	..
40	6·3	5·5	4·9	4·5	**5·7**	4·8	4·3	3·9	4·2	3·5	3·0	..
50	5·7	5·0	4·6	4·2	5·3	4·6	4·1	3·9	**4·3**	3·6	3·2	3·0
60	5·3	4·7	4·3	4·0	5·0	4·4	3·9	3·7	4·1	3·6	3·2	3·2
70	5·0	4·5	4·1	3·8	4·7	4·1	3·8	3·6	3·9	3·5	3·3	**3·3**
80	4·7	4·2	3·9	3·6	4·4	3·9	3·7	3·4	3·8	3·4	3·2	3·1
						Spruce.						
30	3·2	2·4	2·0	1·8	2·0	1·9	1·8	1·7	1·9	1·3	..	..
40	4·2	3·7	3·2	2·8	3·7	3·1	2·8	2·4	2·9	2·5	2·2	..
50	4·6	4·0	3·7	3·3	4·1	3·6	3·2	2·9	3·7	3·2	2·8	..
60	**4·7**	4·1	3·8	3·5	**4·2**	3·7	3·4	3·1	**3·8**	3·4	2·9	..
70	4·5	4·0	3·7	3·5	4·0	3·7	3·4	3·1	**3·8**	3·4	3·0	..
						Scots Pine.						
30	2·1	1·5	..	..	..	..	..	..	..	..	..	..
40	3·5	2·9	..	..	2·7	2·2	..	..	..	..	..	..
50	3·8	3·3	2·9	..	3·2	2·7	..	..	..	..	..	..
60	**3·9**	3·4	3·0	..	3·3	2·8	..	..	..	..	..	..
70	3·8	3·4	3·0	..	**3·4**	2·9	..	..	..	..	..	..
80	3·6	3·3	2·9	..	3·3	2·8	..	..	..	..	..	..
90	3·5	3·2	2·8	..	3·2	2·7	..	..	..	..	..	..
100	3·4	3·0	2·7	..	3·1	2·6	..	..	..	..	..	..

CHAPTER IV.

EXAMPLES OF APPLICATIONS.

THE objects of the forest proprietor, or forester, may vary very considerably. His object may be to aim at the realisation of the most favourable economic results—that is to say, the production of the greatest possible quantity or quality of produce, or he may desire to produce indirect effects, such as the preservation of moisture, the stability of the soil, the effect of forests upon the climate, hygienic effects and similar matters. The realisation of the latter effects frequently, though not necessarily, reduces the financial results of forestry. Still, as forests represent capital, the forester must never lose sight of the economic aspect of the industry. For this purpose, he must study the laws of production, the most suitable method of treatment under a given set of conditions, so as to raise the receipts to the highest point, and practise economy in expenditure. Extravagance has no place in forestry, because the industry gives, in the nature of things, only a moderate interest on the invested capital.

Forest valuation forms the basis upon which rest, to a great extent, the decisions which determine the management of forests, as well as many questions coming under the head of Silviculture. It is not intended to deal in this place with all such matters, but to offer some notes on a few cases which present themselves to the forester in all stages of his practical work. They may serve as guides in dealing with other questions.

If the financial merits of different methods of utilizing land are to be compared, it must be assumed that in each case those conditions exist which render the methods in themselves as profitable as possible. In that case, it may be said that the most profitable method is that which yields the highest profit or the highest mean annual per cent., provided, in the latter case, that the invested capital is of the same amount in each method. If the

capitals are of different amounts, the following cases must be distinguished :—

(1.) The method employing the greater capital is the more profitable if it yields the higher per cent.

(2.) The method with the smaller capital is the more profitable if it yields an equal or a greater amount of interest. If it yields less interest and yet a higher per cent., it cannot be decided off-hand whether it is the more profitable or not, because the total profit depends on two factors, namely, the rate of interest and the amount of the invested capital ; in that case, it is necessary to calculate the actual amount of profit for each method and to compare the one with the other.

These tests may be applied to all questions connected with forest management.

1. Choice between Agriculture and Forestry.

On pages 28 to 31 of Volume I. (4th edition) of the author's "Manual of Forestry," it has been pointed out that, as a rule, forestry must give way to other industries for which the land is required. As regards agriculture, its claims are paramount whenever the production of food is concerned. And yet, in certain cases land may give better financial results if placed under forest than if used for agriculture. The present object is to define the boundary between the two industries from a financial point of view.

The case most frequently occurring is, whether an area of bare land will yield a higher return, say, per acre, if used for agriculture or for forestry ? To answer that question involves a complicated procedure, because there is a great difference between the two industries. In agriculture the returns and expenses occur regularly every year, while in forestry they are spread over a whole rotation, and, to be comparable with those of agriculture, they must be discounted to the commencement of the rotation with a certain rate of interest, which should be the mean annual forest per cent. The following procedure is suggested :—

In the case of agriculture, to do full justice to the problem, it will be necessary to ascertain the local value of the land, say, per acre, and the average net receipts derived from the land. The

latter would involve a complicated investigation of the several items of incomes and outgoings, such as interest on capital outlay, cost of working and administration, taxes, rates, etc., so as to arrive at the true amount of the net income per year from the land. That amount is, however, represented by the letting value of the land, which can be accepted as the interest obtained from the bare land. Assuming, for instance, the local value of the land to be £5 per acre, the letting value to be six shillings, and the proprietor's annual outgoings in the way of taxes, etc., to be two shillings, the net annual interest on a capital of £5 would be four shillings, and the per cent.—

$$p = \frac{\text{net rent}}{\text{capital}} \times 100 = \frac{4}{100} \times 100 = 4 \text{ per cent.}$$

As regards forestry, it is necessary to determine the quality of the locality, the most suitable method of treatment and species, and to use, or construct, a suitable money yield table, as well as to estimate the necessary expenses. The forester will then calculate the maximum soil expectation value with the agricultural per cent., and compare it with the soil cost value. The selection of agricultural or forestal use depends on whether

$$S_c \underset{<}{\overset{>}{=}} S_e.$$

Example.—For agriculture $S_c = 100$ shillings and $p_a = 4$ per cent., as above. For forestry it has been found that the land is best suited for larch, and that the receipts are likely to be those indicated in the money yield table on page 125, III. quality for larch. The cost of formation has been estimated at £5, and the annual net expenses at 6 shillings per acre. The soil values, calculated with 4 per cent., for various rotations have been found to be those given below. From them the 4 per cent. graph has been constructed from which the mean annual forest per cents. for rotations from 30 to 80 years have been obtained :—

Rotation, Years.	Soil Expection Value, shillings.	Mean Forest Per cent.
30	41	3·4
40	115	4·2
50	122	**4·3**
60	106	4·1
70	92	3·9
80	66	3·8

As the soil expectation value under a rotation of 50 years is greater by 22 shillings than the cost value, forestry is more profitable than agriculture, provided that the rotation falls between 40 and 60 years. If a rotation of less than 40 or more than 60 years were adopted, the mean forest per cent. would be less than 4 per cent. ; hence, agriculture would be the more profitable use of the land in that case.

2. Choice of Species.

It is not proposed to deal here with the general suitability of a species for a definite piece of land, or the objects of the proprietor of the land ; that is done in silviculture and management. If, however, two or more species answer well on general grounds, the choice should, in economic forestry, fall on that which gives the best financial results, as indicated, for a certain cost value of the soil, by the highest soil expectation value or, which comes to the same result, by the highest mean forest per cent.

Example.—Compare, for instance, larch III. quality with spruce III. quality. Given a piece of land, value £5 per acre, which suits larch and spruce equally well, and making the calculation with 4 per cent. (which happens to be near the mean forest per cent. of either species), the following results are obtained :—

	Rotation.	Maximum S_e.	P_f. Per cent.
Larch III. quality . . .	50	122	4·3
Spruce III. quality . . .	60	58	3·8

It is evident that it is more profitable to grow larch.

If, on the other hand, the same locality would produce a spruce wood of I. quality, the maximum soil expectation value under a rotation of 60 years would amount to 211 shillings, representing a mean forest per cent. of 4·7, compared with 4·3 per cent. under larch III. quality. It would be more profitable to grow spruce.

3. Choice of Silvicultural System.

Having selected the species to be grown, the forester will consider what silvicultural system is best adapted to realise the objects of the proprietor, taking local conditions into account. As regards the financial results, considerable differences may exist between the different systems. High forest generally yields the greatest quantities and also the highest qualities of

timber ; it also protects, and even improves, the permanent yield capacity of the locality. On the other hand, it requires a considerable capital, especially if a high rotation is adopted. It is obligatory in the case of conifers. There are different kinds of high forest, such as in the clear cutting, the uniform, group and strip-systems of shelterwoods, the selection system and others. Coppice woods are possible only in the case of species which reproduce freely from the stool ; they require a much smaller capital than high forest.

In some cases high forest is financially more profitable, in others coppice woods. The comparative merit in this respect is obtained by ascertaining the maximum soil expectation values or the mean forest per cents. of the competing systems.

4. The Method of Treatment.

From a financial point of view it is essential that the expenses are kept as low as adequate efficiency permits, and that the receipts should be as high as possible, taking into consideration the demands of a sustained yield. In this respect, the following matters are of special importance :—

a. Effect of the Cost of Production.

The principal items of the cost of production are the interest on the cost of the soil, the cost of formation, and the annual expenses for administration, protection, road construction, etc.

The economic value of the soil utilised in forestry is expressed by its maximum expectation value. If the market value of the soil is greater than that, there will be a financial loss, and if it is smaller, a financial gain, being expressed respectively by a lowering or raising of the mean forest per cent., or by a negative or positive profit. Hence, the forester's effort must be to make the expectation value of the soil at least equal to, or, if possible, greater than, the market value. This can be done by careful and judicious management, but only within certain limits. If the market value of the soil reaches, or exceeds, a certain amount, it may be beyond the forester's power to make its utilization in forestry remunerative as compared with its employment in other

industries, such as agriculture. Generally speaking, it may be said that high grade soils give a better return in agriculture, and low grade soils in forestry. The exact limit between the two classes of soil depends on local conditions.

The cost of formation, whether by sowing, planting, or natural regeneration, having to be incurred at the commencement of the rotation, has a most powerful effect upon the financial results. It is essential that it should be kept as low as possible compatible with efficiency. In this respect, many questions must be considered which cannot be dealt with in detail in this place, such as the employment of skilled labourers, the cost of nursery plants, the planting distance, the amount of weeding of young plantations, the employment of small plants, and various other items. The question of the planting distance requires special attention. Wide planting reduces the cost per acre very considerably, but in the case of many species it may result in the production of an inferior class of produce, so that the initial saving may be considerably more than balanced by subsequent loss. As it is generally of importance to cover the soil within a limited number of years, the actual planting distance depends on the rate of growth of the selected species, the quality of produce which it is desired to secure, and the price obtainable for thinned-out material. A considerable saving may be effected by producing a wood by natural regeneration, but, if it is accompanied by a loss of time, it may be cheaper to sow or plant.

The annual expenses do not change much in a well-regulated forest. There may be some moderate difference between those of a high forest as compared with a coppice forest, though, in either case, competent administration is of paramount importance.

b. *Effect of the Intermediate Returns.*

The effect of the intermediate returns upon the financial results depends on the time when they are realised and on the strength and value of the thinnings. The earlier the intermediate returns occur, other matters being the same, the higher will be the expectation value and the lower the cost value.

Example.—A thinning worth 210 shillings usually made in the year 50 in the case of a larch wood III. quality worked under a rotation of 60 years,

and again every 60 years is worth $\frac{210 \times 1{\cdot}04^{10}}{1{\cdot}04^{60} - 1} = 32{\cdot}6$ shillings. If the same thinning were made in the year 40 and again every 60 years, its present value would be $\frac{210 \times 1{\cdot}04^{20}}{1{\cdot}04^{60} - 1} = 48{\cdot}3$ shillings.

Again, the stronger the thinning is made the greater the effect upon the financial result. It would be doubled by cutting 420 shillings worth of wood instead of only 210, provided that the extra heavy cutting does not reduce the final cutting in the year 60. If that were the case, the advantage gained might be more than neutralised, a matter deserving the careful consideration of the forester, especially during the earlier part of the wood's life.

Receipts from minor produce, especially if they occur early, affect the expectation value in the same way as those from thinnings.

5. The Financial Rotation.

By the financial rotation is understood that which coincides with the occurrence of the maximum soil expectation value or, which is the same thing, with the occurrence of the maximum mean annual forest per cent. It changes with the quality, or yield capacity, of the locality. The rotation generally is dealt with in Part III. of this volume.

PART III.

THE FOUNDATIONS OF FOREST MANAGEMENT.

THE FOUNDATIONS OF FOREST MANAGEMENT.

Forest working plans regulate, according to time and locality, the management of forests in such a manner that the objects of the industry are as fully as possible realised. As the latter differ widely, it follows that working plans cannot be drawn up according to any uniform pattern. The working plan for a protection forest or a park-like forest is altogether different from that of a forest which is managed on economic principles. In this volume, only forests of the latter class will be considered, that is to say, it will be explained how forests should be managed so as to produce the best financial results, or the greatest volume, or the most suitable class of produce for a specific purpose.

The yield (or the return) of a forest consists of major or principal, and minor produce. By the former, timber, firewood and bark are understood. It is in the nature of things that forests should yield chiefly such articles ; at the same time, articles of minor produce (such as turpentine, fodder, grazing, fruits, caoutchouc, etc.) are frequently of considerable importance, demanding modifications of that management which would be indicated by considering only the realisation of major produce.

Major produce is derived from the final and intermediate yields. The latter comprise the thinnings and other cuttings which are made from time to time during the course of the life of a wood, while the former is the return yielded by the final cutting of the wood to be followed by a new crop, whether the old crop is removed in one cutting or by a number of successive cuttings, as in the case of natural regeneration under a shelter wood.

The major produce of forests, wood, is one of the indispensable articles of life, but it is bulky and not adapted for a long transport by land. Hence, it must in many cases be produced locally. To this must be added that long periods of time elapse between the planting and harvesting of woods. Both these matters make it desirable that the yield of forests should be continuous and brought

into the market in annually equal, or approximately equal, quantities, necessitating a management based upon the principle of a sustained yield.

Generally speaking, a *sustained yield* is secured if all areas which have been cleared are re-stocked within a reasonable time, and the young woods which spring up properly tended, so that the soil continues to produce crops of wood. At the same time a distinction must be made between—

(1.) The intermittent working, if the successive final returns are separated by a varying number of intermediate years.

(2.) The annual working, if final cuttings occur in each year. If the latter are approximately equal in quantity year by year, the method is called the " equalised annual working."

The regulation of the yield of forests worked intermittently is very simple. It is only necessary to ascertain the most suitable rotation, taking into consideration the objects of management, and to make the intermediate cuttings whenever they are necessary. The matter becomes more difficult when an equal annual yield is expected.

Although the method of annual working, and especially of the equalised annual working, is not an absolute necessity, still it is in the majority of cases highly desirable, more especially where extensive areas are under treatment, or where a steady market has to be regularly supplied. It has considerable advantages, of which the following may be mentioned :—

(1.) It is best adapted to meet the requirements of the market, and therefore favours the development of a regular and steady demand with a sustained competition of purchasers.

(2.) It affords equal employment year after year, and enables the administration to maintain a regular number of workmen and to instruct them thoroughly in their work.

(3.) It secures to the owner an equal, or approximately equal, annual income, and facilitates budget arrangements.

On the other hand, the method has disadvantages, such as :—

(1.) It cannot be introduced without cutting certain woods at an age differing from that which is most desirable, in all cases where a regular series of age gradations does not exist, or where the age gradations are unfavourably distributed over the area.

(2.) Owing to the necessity of bringing annually the same quantity of produce into the market, it interferes with the complete utilization of special demands for forest produce, or the omission of cuttings when the demand is slack.

These remarks show that each of the two methods of working possesses peculiar advantages, and that the choice depends on local conditions. In the majority of cases, the annual working will be found more suitable and profitable, without, however, strictly adhering to it when it would involve sacrifices out of proportion to the general advantages of the method.

Correctly speaking, in order to have equal annual returns it would be necessary to regulate the intermediate cuttings as well as the final returns. Against such an arrangement the following reasons may be given :—

(1.) Areas, which yield equal final returns, do not always give equal intermediate returns.

(2.) Thinnings depend much more than final cuttings on the method of formation and tending ; they must be made when they are necessary, so that the time for their execution can, in many cases, only be determined a short time before they become necessary.

(3.) The yield of intermediate cuttings depends frequently on events which do not occur regularly, or which cannot be foreseen, so that it is almost impossible to estimate it correctly beforehand ; for instance, in the case of windbreak, snow-break, death caused by disease or insects, etc.

Hence, it is desirable to confine the regulation of the annual yield, in the first place, to the final cuttings, and to be satisfied with an approximate equalisation of the intermediate returns, such as will naturally happen if the final cuttings are systematically equalised ; provided always that the thinnings are not made so heavy that they affect the subsequent final returns to an extent which would neutralise the advantages of heavy thinnings.

If a forest is to yield a return, either annually or periodically, it must be in a certain state. In order to determine what this state should be under a given set of conditions, it is useful to construct an ideal pattern, such as would be presented by a forest which has

grown up uninfluenced by external interfering circumstances. The ideal state differs, of course, for every different method of treatment, in accordance with the objects at which the management aims. In all these cases, a forest which corresponds in every way to the objects of management is called a *normal forest.* It enables the forester to study the laws which must govern the management, and it serves as an ideal to be aimed at, though it may never be altogether reached, or, if established, not permanently maintained.

The normal state of a forest, under a given set of conditions, depends chiefly on the presence in it of—

(1.) A normal increment.

(2.) A normal distribution of the age classes.

(3.) A normal growing stock.

By *normal increment* is understood that which is *possible,* given a certain locality, species and rotation. An abnormal increment may be caused by faulty formation, faulty treatment, injurious external influences and also, for the time being, by a preponderance of certain age classes and a deficiency of others.

By a *normal distribution of age classes* is understood a series of age gradations or classes so arranged that at all times, when cuttings are to be made, woods of the normal age are available of sufficient extent and in such a position that no obstacles to their cutting exist.

The *normal growing stock* is that which is present in a forest, in which the age gradations are normally arranged and show the normal increment. It can, however, also be present (in quantity) in an abnormal forest, if the deficiency of some woods is made good by a surplus in others.

For the strictly annual working and the clear cutting system, a forest is, therefore, normal if it consists of a series of fully stocked woods equal in number to the number of years in the rotation and of the same yield capacity, so that each year a wood of the normal age can be cut, and that the returns are equal, at any rate in quantity if not in value.

From a financial point of view, the further condition must be added that there should be no woods in the forest the current increment per cent. of which has sunk below the mean annual forest per cent. ${}^{m}p_{f}$.

In accordance with these definitions, the following matters demand special attention :—

(1.) The increment.

(2.) The rotation, or the normal age at which woods should be cut over.

(3.) The normal age gradations or classes.

(4.) The normal growing stock.

(5.) The normal yield.

(6.) The relations which exist between growing stock, increment and yield.

CHAPTER I.

THE INCREMENT.

Every tree or wood may lay on three different kinds of increment :—

(1.) Volume or quantity increment.

(2.) Quality increment } Also called the value increment.
(3.) Price increment }

SECTION I.—THE VOLUME INCREMENT.

By volume increment is understood the increase in the quantity of wood produced annually, periodically, or during the whole lifetime of a tree or wood, called respectively the current annual increment (C.A.I.), and the mean annual increment (M.A.I.) ; the latter may refer to a limited number of years, a period, or to the total increment laid on by a tree or wood. The increment is measured by the solid cubic foot or by the stacked cubic foot. The manner of determining the increment is given in Forest Mensuration. For the purpose of forest management, it should be mentioned that for short periods, say 5 to 10 years, the periodic mean annual increment is frequently accepted as the current annual increment without introducing any appreciable error. The calculation of the increment may refer to the final yield only, or to the intermediate yields, or to both together.

1. The Volume Increment of Single Trees.

This is produced by an annual extension of the crown and roots, and by the addition of a new layer between wood and bark all over the stem, branches and roots. As a general rule, the stem, or trunk, is the most important part of the tree, and the forester is specially interested in the height and diameter (or girth) growth.

Height Growth.—It is explained in silvicultural works that the energy of height growth differs not only according to species, but also, in the case of one and the same species, according to the

productive power of the locality, the age of the tree and the method of treatment; there is, further, a considerable difference, in the case of most species, between seedlings and coppice shoots.

The table and Fig. 42 (pp. 174–5) exhibit the height growth of some of the more important species grown in Britain and on the Continent, the data referring in each case to localities of the first quality class, and it is assumed that the trees have grown in fairly stocked woods raised from seedlings. The data for larch, Norway spruce and Scots pine have been taken from the yield tables published by the Forestry Commissioners in *Bulletin* No. 3. Unfortunately, British height growth tables for the other species are not yet available; hence a comparison of one group with the other is only approximately correct. In the illustration some data of the height growth of Vancouver Douglas fir in Britain have been added, which show that this tree grows more rapidly than any other tree which can be grown in Britain.

It should be stated, in the first place, that larch and spruce grow in the early part of their life more rapidly in Britain than on the Continent, and that Scots pine grows more slowly. All three grow quicker than beech, oak and silver fir during youth, and up to the age of 60 years. From that age onward, considerable changes take place. While larch is the fastest growing tree to begin with, it is caught up and passed by spruce at the age of about 50 years. At the age of about 65 Scots pine is passed by beech and oak, while silver fir passes oak a few years afterwards, and gradually also beech. At this time beech passes oak, and it is itself passed by silver fir shortly afterwards. The latter species catches up, and passes, larch at the age of nearly 120 years. In consequence of these changes, the final order at the age of 120 years is as follows:—Vancouver Douglas, Norway spruce, silver fir, larch, beech, oak and Scots pine. A similar relative height growth occurs in the other quality classes. On the whole it is, however, somewhat modified by local conditions.

It should be noted that the actual height growth is, in the case of many species, considerably influenced by the density of a forest crop. A fair degree of density accelerates it, while too dense stocking retards it, especially in the case of broad-leaved species, which have a tendency to become flat headed at a comparatively early age.

TABLE SHOWING THE COMPARATIVE HEIGHT GROWTH OF SOME EUROPEAN SPECIES, IN FEET.

Age, Years.	Data taken from British Yield Tables.			Data taken from Continental Yield Tables.			Age, Years.
	Larch.	Norway Spruce.	Scots Pine.	Silver Fir.	Beech.	Oak.	
10	18	12	13	3	6	10	10
20	40	31	26	9	18	25	20
30	58	51	40	18	31	37	30
40	71	66	51	30	45	48	40
50	80	80	60	45	56	58	50
60	87	91	67	58	67	67	60
70	94	100	72	71	76	73	70
80	100	*108*	77	82	85	79	80
90	*104*	*114*	81	91	92	83	90
100	*107*	*118*	84	98	98	87	100
110	*108*	*122*	*86*	104	104	91	110
120	*109*	*126*	*87*	109	107	94	120

The data printed in italics for Scots pine beyond the age of 100, for larch beyond the age of 80, and for spruce beyond the age of 70 years, are estimates based on the increment laid on immediately before those ages.

The relative height growth is of paramount importance in silviculture, and especially in the formation and maintenance of mixed woods. It indicates the species which can be successfully mixed, as well as the measures to be taken to protect the slower growing species against suppression by their faster growing companions. As shown in Forest Mensuration, height growth is also used to distinguish between the different quality classes of the locality.

The periods at which the current annual and mean annual height increments reach their maxima are also of great interest to the forester, but the available data give somewhat wide limits for these periods. In a general way, the maxima occur earlier in the case of light-demanding species than in that of shade bearers. They occur, according to the British yield tables, at the following ages :—

Quality Classes.	Current Annual Increment.				Mean Annual Increment.			
	I.	II.	III.	IV.	I.	II.	III.	IV.
Larch	20	20	25	30	30	30	35	35
Norway spruce..	25	25	30	30	30	35	40	45

It will be noticed that the maxima occur earlier on good quality than on inferior soils.

In the case of teak (*Tectona grandis*), the current annual height increment generally reaches its maximum during the first five

DIAGRAM SHOWING THE COMPARATIVE HEIGHT GROWTH.

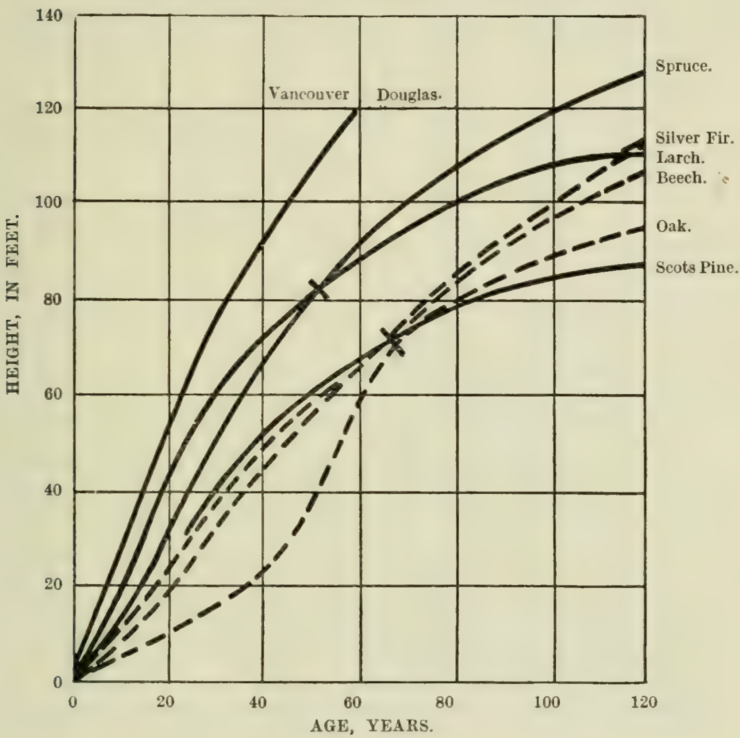


Fig. 42.

years of the tree's life. Deodar (*Cedrus Deodara*) shows a height growth similar to that of spruce. Sal (*Shorea robusta*) has a remarkably even rate of growth up to the age of 80 to 100 years.

Coppice shoots show generally the greatest height growth during the first few years of their existence ; the rate of increment begins to fall off early, nor do such shoots, few cases excepted, reach the same ultimate height as seedling trees.

Diameter, or Girth, Increment.—This depends on the quality of

the locality and the size and activity of the leaf-surface. As a consequence, free-growing trees increase more rapidly in diameter than those grown in fully stocked woods. At the same time, the position of the leaf-surface on the stem is of importance. Trees with the crown coming down to the ground are more tapering than those with the crown restricted to the upper part of the stem, which show a more cylindrical shape. Hence, the forester aims at killing

Table showing the Diameter Growth in Inches of some European Species of Trees in Fairly Fully Stocked Woods.

Age, Years.	Data taken from British Yield Tables.			Data taken from Continental Yield Tables.			Age, Years.
	Larch.	Norway Spruce.	Scots Pine.	Silver Fir.	Beech.	Oak.	
10	..	..	..	0·5	0·7	1·0	10
20	5·1	..	..	1·3	1·7	2·4	20
30	7·6	7·3	5·7	2·5	3·0	4·3	30
40	9·6	10·5	8·0	4·0	4·5	6·1	40
50	11·1	13·4	9·9	5·6	6·3	8·2	50
60	13·4	15·9	11·5	7·5	8·0	9·9	60
70	14·7	17·8	13·1	9·6	9·5	11·4	70
80	15·9	*19·7*	14·7	11·7	10·9	12·8	80
90	*17·0*	*21·5*	15·9	14·2	12·2	14·2	90
100	*18·0*	*22·5*	16·9	16·2	13·5	15·5	100
110	*19·0*	*24·0*	*18·0*	17·5	14·6	16·9	110
120	*20·0*	*25·0*	*19·0*	18·3	15·6	18·4	120

The data for larch beyond the age of 80, for spruce beyond 70 years, and for Scots pine beyond 100 years are estimates based on the immediately preceding increment. They are printed in italics.

A comparison of the British yield tables with the German tables shows that larch, spruce and Scots pine show a more rapid diameter increment in the former country.

the lower branches naturally, which he achieves by maintaining an appropriate density of stocking until towards the latter part of the life of his woods. Whenever the object is to produce a high quality of timber, he sees that a young wood establishes a complete leaf canopy at an early age, and subsequently he regulates the thinnings so that at all times each tree has the most suitable growing space. A tendency has been perceptible of late years to introduce wide planting so as to reduce the initial cost, to be followed by very heavy thinnings. This may be justifiable where the production of volume only is aimed at, but, in the author's

view, it is a serious mistake where high-class timber is to be produced. In the latter case, a high form factor of the stem should be the object of the forester.

The appended table and Fig. 43 show the diameter growth of some species.

Diagram showing the Relative Diameter Growth.

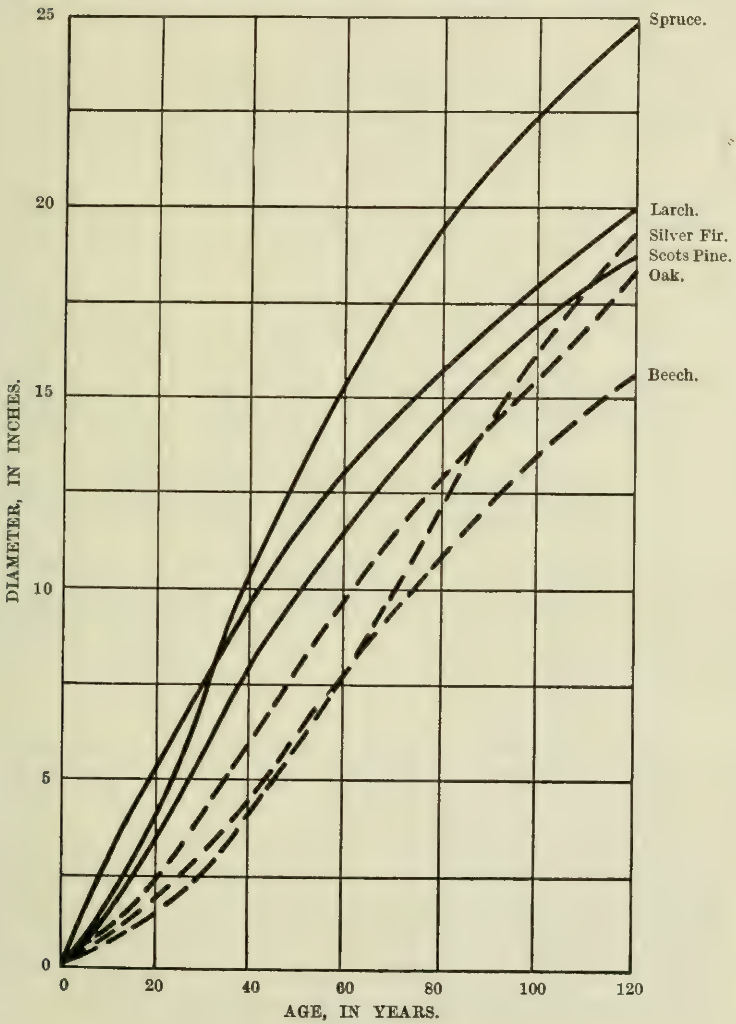


Fig. 43.

2. The Volume Increment of Whole Woods.

The various methods of determining the volume and increment of woods are dealt with in Forest Mensuration. Here only those points will be considered which are of special interest to the manager of a forest. The increment of a wood consists, during the first part of its life, of the full increment of the individual trees. As soon as the trees close overhead, the extension of the crown is impeded, and a struggle for existence sets in. As long as the degree of density is moderate, the height growth is not reduced ; a moderate degree of density of the leaf canopy actually encourages it. On the other hand, too dense a stocking may cause a reduction of the diameter growth. Although, during this period, the individual tree may lay on less increment than it would do in a free position, a fully stocked wood can have, and generally has, a larger increment per unit of area than an open wood, because the total increment is equal to the mean increment per tree multiplied by the number of trees per unit of area. What degree of density

Table showing the Volume production of some European Species. I. Quality, Timber only, in Cubic Feet. Woods fully Stocked.

Age. Years.	Data taken from British Yield Tables.			Data taken from German Yield Tables.			Age. Years.
	European Larch.	Norway Spruce.	Scots Pine.	Silver Fir.	Beech.	Oak.	
10	600	..	..	..	..	..	10
20	1,640	1,500	800	..	..	560	20
30	3,245	3,910	2,050	500	690	1,800	30
40	4,690	6,585	3,495	1,760	2,070	3,320	40
50	5,940	9,055	4,805	4,090	3,860	4,780	50
60	7,145	11,175	5,960	6,690	5,690	6,180	60
70	8,260	12,780	7,045	9,950	7,500	7,480	70
80	9,160	*14,300*	8,040	13,630	9,250	8,710	80
90	*10,000*	*15,800*	8,940	17,260	10,880	9,900	90
100	*10,800*	*17,250*	9,695	20,360	12,430	10,980	100
110	*11,500*	*18,650*	*10,400*	22,710	13,850	11,990	110
120	*12,000*	*20,000*	*11,000*	24,630	15,170	12,950	120

The data for larch beyond the age of 80, for spruce beyond 70, and for Scots pine beyond 100 years are estimates, based on the immediately preceding increment; they are printed in italics. The volume production includes all thinnings.

of a wood gives the maximum of production has been much studied, but in the case of many species final conclusions have not yet been reached. In the meantime, it should be remembered that a fairly full stocking encourages height growth, decreases the tapering of the stem and kills the lower branches, thus producing a high quality of timber.

While the loss of material is very small in the case of trees

VOLUME PRODUCTION—TIMBER ONLY.
I. QUALITY CLASS.

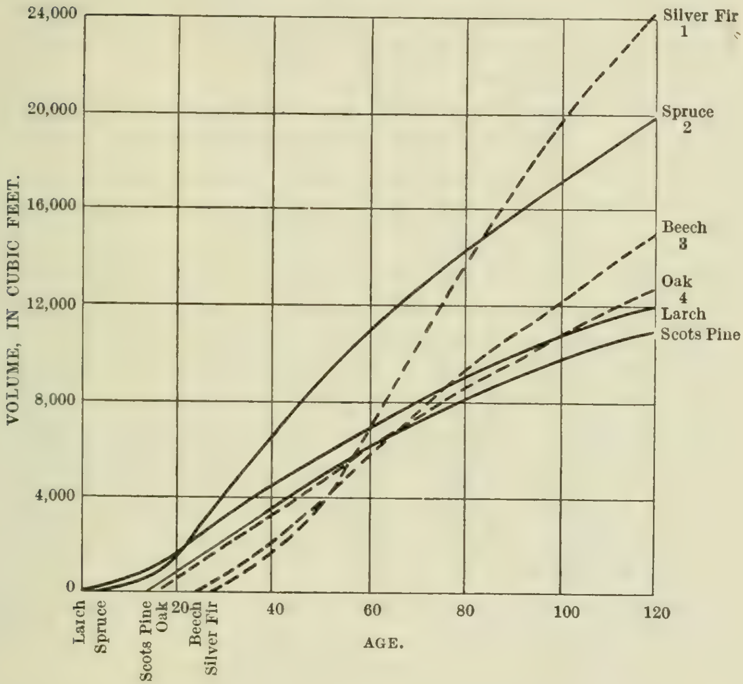


Fig. 44.

grown in the open, it becomes very considerable in fully stocked woods. Not only do the lower branches die, but the greater number of the trees must be removed, because they are gradually overtopped, suppressed and finally killed by surrounding trees of stronger height growth ; such trees form, ordinarily, the material removed in thinnings. In fully stocked woods, a distinction is

made between the dominating trees and the rest of the stocking; the former are called the major or primary part of the growing stock, and the latter the minor or secondary part. As the life of the wood advances, not only the latter, but also a considerable portion of the previously dominating trees will be removed in the thinnings, in the same degree as they lose their dominating character and join the secondary part of the growing stock.

The appended table and Fig. 44 exhibit the volume production of some European species. They represent the volume of timber only produced on first class-localities. The Continental yield tables used are those for silver fir by Lorey, for beech by Schwappach and for oak by Wimmenauer.

It will be observed that at the age of 40 years the comparative production is as follows :—Silver fir, 1,760 cubic feet; beech, 2,070; oak, 3,220; Scots pine, 3,495; larch, 4,690; Norway spruce, 6,585. Then great changes take place in the relative position, so that at the age of 80 years the sequence is as follows :—Scots pine, 8,040; oak, 8,710; larch, 9,160; beech, 9,250; silver fir, 13,630; spruce, 14,300. This relative position is again altered and the differences in production are further increased, so that the position at the age of 120 years is as follows: Scots pine, 11,000; larch, 12,000; oak, 12,950; beech, 15,170; spruce, 20,000; silver fir, 24,630. It should, however, be noted that the volumes of larch beyond 80, of spruce beyond 70, and of Scots pine above 100 are estimates. Further experience may show that the volume production of spruce at an advanced age may be above that now estimated.

The progressive increment per acre and year is shown in the table on next page.

The given data justify the following conclusions :—

(1.) The current annual increment of light-demanding species (larch, Scots pine and oak), and also of the moderate shade bearer, spruce, rises rapidly after the first few years and reaches its maximum generally about the time when the height growth culminates. In the case of shade bearers, the maximum volume increment occurs later than the maximum height growth, in beech by 20 years and in silver fir by 40 years.

(2.) The mean annual increment keeps at first below the current annual increment ; the two become equal some time after

TABLE SHOWING THE CURRENT ANNUAL INCREMENT (C.I.) AND THE MEAN ANNUAL INCREMENT (M.I.) PER ACRE AND YEAR, INCLUDING THINNINGS. TIMBER DOWN TO 3 INCHES AT SMALL END, IN CUBIC FEET. I. QUALITY.

Age. Years.	Data taken from British Yield Tables. Measured under Bark.						Data taken from German Yield Tables. Measured over Bark.						Age. Years.
	Larch.		Norway Spruce.		Scots Pine.		Silver Fir.		Beech.		Oak.		
	C.I.	M.I.	C.I.	M.I.	C.I.	M.I.	C.I.	M.I.	C.I.	M.I.	C.I.	M.I.	
10	..	..	..	..	..	..	..	..	..	..	..	..	10
	96										56		
20		78	..	*75*	..	*40*	..	..	..	..		28	20
	168		*241*		*125*		50		69		124		
30		108		131		68		17		23		60	30
	144		**267**		**144**		126		138		**152**		
40		117		165		87		44		52		83	40
	125		247		131		210		179		146		
50		**119**		181		96		82		77		96	50
	120		212		115		260		**183**		140		
60		**119**		**186**		99		111		95		103	60
	111		160		108		326		181		130		
70		118		183		**101**		142		107		107	70
	90		*152*		99		**368**		175		123		
80		115		*179*		100		170		116		109	80
	84		*150*		90		363		163		119		
90		*111*		*175*		99		192		121		**110**	90
	80		*145*		75		310		155		108		
100		*108*		*172*		97		204		124		110	100
	70		*140*		*70*		235		142		101		
110		*105*		*169*		*95*		**206**		**126**		109	110
	50		*135*		*60*		192		132		96		
120		*100*		*167*		*92*		205		126		108	120

the current increment has passed its maximum, after which date the mean increment is larger than the current increment. Naturally, the mean increment reaches its maximum at the time when it is equal to the current increment.

(3.) During the period between the two maxima the current increment is falling and the mean increment rising.

The appended illustration for larch (Fig. 45) will show this :—

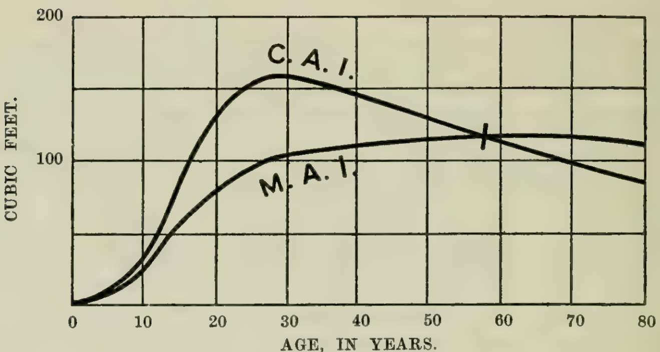


Fig. 45.—Relation of C.A.I. and M.A.I. of Larch.

(4.) Whenever the object of management is to obtain the greatest volume production, the rotation should coincide with the year in which the mean annual increment culminates. Taking the data for larch as an example, the current increment culminates in the year 29 and the mean increment in the year 58; hence, in the course of 58 years two crops 29 years old can be grown giving a total volume of $2 \times (105 \times 29) = 6{,}090$ cubic feet, while one rotation of 58 years gives $119 \times 58 = 6{,}902$ cubic feet, or 812 cubic feet more.

The data given above for the best quality class exhibit the differences in height, diameter, and volume production of the more important European species. It stands to reason that the data diminish according to the reduction of the quality. On this point a reference to the yield tables given in Appendix IV. is invited.

3. The Volume Increment per Cent.

So far the increment has been expressed in actual volume or cubic feet. In addition, it is useful to ascertain the proportion which exists between the total volume of the tree or wood at a certain age and the increment laid on during one or several years before or after that age. In order to express that proportion independently of the actual volume, it is usual to give it in per

cents. and to call it the "increment per cent." By this is understood the current annual or periodic increment which is laid on by every 100 units of volume.

By analogy with what has been said in Part II., let ${}^{m}V$ be the volume of a wood in the year m, and ${}^{m+n}V$ the volume in the year $m + n$, then :—

$$ {}^{m+n}V = {}^{m}V \times 1{\cdot}0p_v^n \text{ and } {}^{Current}p_v = 100 \times \sqrt[n]{\frac{{}^{m+n}V}{{}^{n}V}} - 100, \text{ or} $$

$$ \log. (100 + p_v) = 2 + \frac{\log. {}^{m+n}V - \log. {}^{m}V}{n}, \text{ and} $$

Pressler's approximate formula becomes

$$ {}^{Current}p_v = \frac{{}^{m+n}V - {}^{m}V}{{}^{m+n}V + {}^{m}V} \times \frac{200}{n}. $$

Example :—

Let the volume at the age of 40 be = 2,290 cubic feet, and in the year 50 = 3,270 cubic feet, then

$$ \text{Log. } (100 + p_v) = 2 + \frac{\log. 3{,}270 - \log. 2{,}290}{10}, \text{ and } p_v = 3{\cdot}53 \text{ per cent.}; $$

and according to Pressler's formula,

$$ \frac{{}^{m+n}V - {}^{m}V}{{}^{m+n}V + {}^{m}V} \times \frac{200}{n} = \frac{3{,}270 - 2{,}290}{3{,}270 + 2{,}290} \times \frac{200}{10}, \text{ and } p_v = 3{\cdot}53. $$

If a thinning has been made during the n years, its volume must be added to that of ${}^{m+n}V$.

The increment per cent., p_v, is very large during the early youth of a wood, or tree, but as the volume increases with advancing age, while the annual increment does not increase in anything like the same proportion, and in fact begins to decrease comparatively early, it follows that the increment per cent. becomes smaller year by year. Heavy thinnings may produce an exception to that rule, as they would temporarily reduce the producing capital. By calculating the volume increment per cent. with formula 2 for various periods, the following results are obtained :—

Period 20—30 = 9·28 per cent.	Period 50—60 = 2·76 per cent.
,, 30—40 = 5·35 ,,	,, 60—70 = 2·31 ,,
,, 40—50 = 3·53 ,,	,, 70—80 = 1·75 ,,

It remains to add that the above formulas can also be used to determine the height, diameter and basal area increment per cent.

SECTION II.—THE QUALITY INCREMENT PER CENT.

By quality increment is understood the increase in the value per unit of volume. It is produced, in the first place, by larger pieces of timber frequently fetching higher prices per unit of measurement, and secondly by a reduction of the cost of harvesting per unit of measurement. Quality increment is independent of any alteration in the general price of forest produce.

If, in the course of n years, the net value of the unit of volume rises from ${}^{m}Q$ to ${}^{m+n}Q$, then the quality increment per cent. is obtained by the formula—

$$ {}^{m+n}Q = {}^{m}Q \times \left(1{\cdot}0p_q\right)^n ; $$

and

$$ p_q = 100 \left(\sqrt[n]{\frac{{}^{m+n}Q}{{}^{m}Q}} - 1 \right); $$

and

$$ \log. (100 + p_q) = 2 + \frac{\log. {}^{m+n}Q - \log. {}^{m}Q}{n}. $$

An approximately correct value for p_q is obtained by the formula—

$$ p_q = \frac{{}^{m+n}Q - {}^{m}Q}{{}^{m+n}Q + {}^{m}Q} \times \frac{200}{n}. $$

The quality increment may be rising, falling, or its movements may be more or less irregular ; hence, it must be ascertained in each case.

Woods grown for *firewood* show only little or no quality increment after middle age ; except, perhaps, in so far as the percentage of stem-wood increases. The latest investigations seem to indicate even that wood taken from middle-aged trees has a higher heating power than wood taken from older trees, although the latter may be perfectly sound.

Matters are different in the case of *timber forests ;* here the

quality increment rises, in the majority of cases, at any rate, beyond middle age and frequently to an advanced age, because :

(1.) Trees of large dimensions are, up to a certain limit, more valuable per unit of volume than those of small dimensions, though exceptions to this rule occur frequently.

(2.) The percentage of timber to firewood increases, at any rate up to a certain age.

The quality increment per cent. sinks, on the whole, with advancing age, though more or less irregularly ; it can become nil and even negative if the timber commences to decay.

Example.—A Scots pine wood 60 years old contains—

Timber = 3,300 cubic feet, worth 4*d.* per cubic foot.
Firewood = 760 ,, ,, ,, 1*d.* ,, ,,

Hence, mean quality—

$$^{m+m}Q = \frac{3{,}300 \times 4 + 760 \times 1}{4{,}060} = 3{\cdot}44 \text{ pence.}$$

The same wood in the year 70 has—

Timber = 3,820 cubic feet, worth 5*d.* a cubic foot.
Firewood = 710 ,, ,, ,, 1*d.* ,, ,,

Hence—

$$^{m+n}Q = \frac{3{,}820 \times 5 + 710 \times 1}{4{,}530} = 4{\cdot}37 \text{ pence.}$$

And

$$4{\cdot}37 = 3{\cdot}44 \times 1{\cdot}0p_q{}^{10}$$

$$p_q = 100\left(\sqrt[10]{\frac{4{\cdot}37}{3{\cdot}44}} - 1\right)$$

$$\log.\,(100 + p_q) = 2 + \frac{\log.\,4{\cdot}37 - \log.\,3{\cdot}44}{10}.$$

And

$$p_q = 2{\cdot}42 \text{ per cent.}$$

Approximate value—

$$p_q = \frac{4{\cdot}37 - 3{\cdot}44}{4{\cdot}37 + 3{\cdot}44} \times \frac{200}{10} = 2{\cdot}38 \text{ per cent.}$$

What has been said above can also be applied to the intermediate returns. Indeed, the quality increment of that part of a wood which yields the thinnings can be very considerable, especially while the wood is still young. Here, a few years' extra growth may cause a great rise in the quality per unit of measurement. On the other hand, if thinnings are kept over too long, they interfere with the proper development of the major part of the wood ; hence, extremes in this respect must be avoided.

SECTION III.—THE PRICE INCREMENT PER CENT.

By price increment is understood the increment caused by a change in the price of forest produce generally, independent of the accompanying quality increment. It can be positive, nil, or negative.

Example.—A hitherto inaccessible forest is brought into communication with a large town by the construction of a railway; the increase in the prices of the produce of the forest represents the price increment, which in this case is positive.

Or, owing to an increased import of forest produce, the price of the home production falls generally; this represents a negative price increment.

The price increment depends partly on the forester, and partly on external causes over which he has little or no control. Of the former class of causes are, for instance, the construction of good roads, development of industries which consume forest produce, improvement in the general management leading to a higher net value per unit of measurement.

It is out of the question to construct a law showing the changes in price. In some cases, such changes affect all classes of produce, in others only certain kinds. In any circumstances, it is almost impossible to foresee them, except in special definite cases. At the same time, the price increment is of considerable importance, as it affects the financial ripeness of woods, and in this way influences the lines upon which the management of the forest should proceed.

The price increment is calculated in the same way as the quality increment. If ${}^{m}S$ represents the value of the unit of measurement at the present time, and ${}^{m+n}S$ the corresponding value after n years, the price increment is $= {}^{m+n}S - {}^{m}S$, and

$${}^{m+n}S = {}^{m}S \times 1{\cdot}0p_s{}^{n}$$

$$\mathbf{p_s = 100\left(\sqrt[n]{\frac{{}^{m+n}S}{{}^{m}S}} - 1\right)},$$

$$\log.\ (100 + p_s) = 2 + \frac{\log.\ {}^{m+n}S - \log.\ {}^{m}S}{n}.$$

Again, the approximate value—

$$\mathbf{p_s = \frac{{}^{m+n}S - {}^{m}S}{{}^{m+n}S + {}^{m}S} \times \frac{200}{n}}.$$

SECTION IV.—COMBINATION OF THE THREE INCREMENT PER CENTS.

A forest of the present value of ${}^{m}F$, working with the three per cents. p_v, p_q, and p_s, increases in one year to

$$ {}^{m+1}F = {}^{m}F \times 1{\cdot}0p_v \times 1{\cdot}0p_q \times 1{\cdot}0p_s, $$

and, if

$$ 1{\cdot}0p_v \times 1{\cdot}0p_q \times 1{\cdot}0p_s \text{ is placed} = 1{\cdot}0p_f, $$

then

$$ {}^{m+1}F = {}^{m}F \times 1{\cdot}0p_f, \text{ and } {}^{m+n}F = {}^{m}F \times 1{\cdot}0p_f^n. $$

Out of this is obtained the value of ${}^{current}\,p_f^n$ during n years :—

$$ {}^{current}\,p_f = 100 \times \sqrt[n]{\frac{{}^{m+n}F}{{}^{m}F}} - 100, $$

and

$$ \log.\ (100 + p_f) = 2 + \frac{\log.\ {}^{m+n}F - \log.\ {}^{m}F}{n}. $$

This is the formula for the forest per cent. given at page 139. As there, so here, the value of ${}^{m}F$ is taken as the utilization value of the growing stock + the value of the soil. For an example, see Part II., page 141.

CHAPTER II.

THE ROTATION.

By rotation is understood the period of time which elapses between the formation of a wood and the time when it is finally cut over. The determination of the length of the rotation is one of the most important measures in forest management. It depends on the objects which the proprietor is aiming at, and these differ with every change of conditions. In some cases the proprietor desires to realise indirect effects, such as the protection of the soil, amenities, hygienic effects, etc., in which high rotations may be indicated. In other cases, the economic aspects of forestry are paramount, such as the production of the greatest quantity or highest quality of produce, the production of a definite class of timber, or high financial results. Accordingly, the forester arranges the rotations under various titles, such as :—

(1.) The financial rotation,
(2.) The rotation of the highest income,
(3.) The rotation of the highest volume production,
(4.) The technical rotation,
(5.) The physical rotation,

and various others of minor importance. As forests represent capital, they are, in economic forestry, expected to yield an adequate return. Hence, the financial rotation has been placed first; by it the financial loss involved in the adoption of a different rotation is measured.

1. The Financial Rotation.

By it is understood the rotation which, after allowing compound interest on all outgoings and receipts, gives the highest net profit over and above a fixed per cent., or the highest mean annual forest per cent. The methods of calculating either the one or the other have been explained in Forest Valuation.

The profit is given by the formula—

$$\text{Profit} = S_e - S_c, \text{ respectively} = F_e - F_c,$$

calculated with a fixed per cent. (see pages 136–7).

The maximum mean annual forest per cent. is obtained by calculating the soil expectation values with various per cents. and constructing a graph, from which the per cents. corresponding to varying soil cost values can be read off (see pages 142–6).

Owing to the uncertainty of the future returns and expenses, from which these calculations are made, the financial rotation can only approximately be ascertained. Moreover, it changes with every change of conditions. In these circumstances, it can serve only as a general guide. Its accuracy will increase with the perfection of the available yield tables. It should also be noted that it is impossible to forecast prices in the future; they may rise or fall. Hence, all calculations should be made with present prices, or those which prevailed in the immediate past. All these matters make it desirable to fix the actual financial rotation somewhat higher than the calculated number of years.

The growing stock of a wood has, in the majority of cases, little value during the first part of the rotation, so that the yield would not even cover the cost of harvesting, and the expectation value of the soil would be a negative amount. With advancing age it should become positive, and increase in value until it reaches its maximum amount, after which time it decreases. A second maximum is sometimes reached, owing to a sudden increase in the price per unit of measurement of the yield. In any case, under a high rotation the expectation value would, under ordinary conditions, again become negative.

Example.—Calculating the expectation value for larch III. quality with 4 per cent., the following values are obtained if $S_c = £5$:—

Rotation.	Soil Expectation Value.	Mean Forest Per Cent.
30	41 shillings.	3·4 per cent.
40	115 ,,	4·2 ,,
50	122 ,,	4·3 ,,
60	106 ,,	4·1 ,,
70	92 ,,	3·9 ,,
80	66 ,,	3·8 ,,

In this case, the maximum is reached under a rotation of 50 years, or perhaps a couple of years before that time. This rotation is the "financial rotation," being the most profitable from a financial point of view. The forester must then consider whether, and to what extent, a deviation from the financial rotation is required, so as to realise the objects of the proprietor.

Deviations from the financial rotation may be due to various considerations, as indicated above. In all such cases the effect is a reduction of the forest per cent. If, for example, the rotation in the case of larch III. quality is raised from 50 to 80 years, the mean per cent. is reduced from 4·3 to 3·8 per cent.

The actual length of the financial rotation differs very considerably. Generally speaking, it may be said that the financial rotation is *low* in localities of a high yield capacity; where an increase in the price per unit of volume ceases at a comparatively early age, such as localities where only firewood is saleable; where trees of small dimensions can be sold at timber prices, such as in mining and hop-growing districts. The financial rotation is *high* in localities with an unfavourable soil and climate, such as high and exposed situations where the trees take a longer time to reach marketable dimensions; in thinly populated districts where prices generally rule low for small dimensions, while large timber can be exported to other better-paying markets.

The length of the financial rotation as obtained by a first calculation is subject to correction, because it is based upon prices obtainable for the various classes of produce at the time. These may be changed if the financial rotation differs from that hitherto followed. If the calculated financial rotation is lower than that existing, and the former is introduced, more small and less large timber is produced, which may cause a fall in the average price of the produce. The reverse effect will be produced if the financial rotation is the higher of the two. In either case, a change in the rotation will be accompanied by a change in the permanent growing stock. The difference between the old and the new growing stock must be removed in the one case or saved up in the other; in other words, either more or less timber than previously is thrown upon the market for a time, which may further disturb prices.

In these circumstances, any change in the rotation should be introduced cautiously, and, on the whole, it is desirable to keep somewhat above the theoretical financial rotation. If the change refers to a small area, it can be carried out at once, provided the demand for produce is sufficiently large to absorb the extra cuttings without any appreciable change in prices. If the forest is of some extent and the demand for produce uncertain, it is preferable to make the change gradually, so as to spread the extra supply of produce over a number of years, or to bring up a deficient growing stock to the proper amount by moderate annual savings.*

2. The Rotation of the Highest Net Income.

By this is understood the rotation which yields the highest net income calculated without interest and irrespective of the time when the items of income and costs occur. The average net annual income is obtained by dividing the sum of all incomes, minus the sum of all costs of one rotation, by the number of years in the rotation according to the formula :—

$$\text{Mean annual net income} = \frac{Y_r + T_a + T_b + \ldots + T_q - c - r \times e}{r}$$

The rotation for which this expression reaches the maximum amount is the rotation of the highest net annual income. It occurs, as a rule, a considerable number of years beyond the financial rotation.

Example.—From the money yield table for larch III. quality the following amounts for the net annual income are obtained, to which the mean forest per cents. for the several rotations have been added :—

Rotation.	Mean Annual Net Income.	Mean Forest Per Cent.
30	25 shillings.	3·4 per cent.
40	28 ,,	4·2 ,,
50	38 ,,	4·3 ,,
60	46 ,,	4·1 ,,
70	55 ,,	3·9 ,,
80	62 ,,	3·8 ,,

* In an article published by the Author in 1865, it was shown that a moderate reduction in the price of the produce placed on the market may be financially preferable to leaving surplus growing stock in the forest. (See *Allgemeine Forst und Jagd Zeitung* of 1865.)

It will be observed that the annual net income is still rising under a rotation of 80 years, and likely to do so for another 10 or 20 years—in fact, until the increase in the expenses overtakes that in the volume and quality of the increment. At the same time, it will be observed that the maximum mean annual forest per cent. occurred under a rotation of 50 years with 4·3 per cent., and that it had fallen to 3·8 per cent. under a rotation of 80 years, involving a considerable financial loss. This loss will further increase with a further rise of the rotation, and it represents the penalty which the proprietor has to meet for going beyond the financial rotation. At the same time, other considerations may, and in many cases will, justify the adoption of such a course.

3. The Rotation of the Greatest Production of Volume.

This is the rotation under which a forest yields the greatest quantity of material per unit of area. It coincides with the year in which the mean annual volume increment culminates.

Let the volume of the final yield be V_r, and the volumes of the thinnings in the years $a, b, \ldots q$ be represented by $V_a, V_b, \ldots V_q$, then the rotation of the greatest volume production is that under which the value $\frac{Y_r + V_a + V_b \ldots + V_q}{r}$ becomes a maximum. The calculation can be made for timber and firewood or for timber only.

Example.—Taking the data for larch III. quality, the amounts are :—

Rotation.	Yield, c'.	Rotation.	Yield, c'.
30	51	60	75
40	65	70	77·2
50	71	80	76·9

The maximum occurs under a rotation of 70 years, which is 20 years above the financial rotation, involving a reduction of the mean forest per cent. from 4·3 to 3·9 per cent.

4. The Technical Rotation.

By this is understood the rotation under which a forest yields the most suitable material for a special purpose, such as, for

instance, for general construction, shipbuilding, railway sleepers, telegraph or hop poles, mining props, tanning bark, fuel, etc.

As the objects of management and the purposes for which the material is required vary much, the technical rotation may occur at any age, before, at and after the age of the financial rotation.

5. The Physical Rotation.

This term is applied to various conditions. It may be that rotation which coincides with the natural lease of life of the trees, as in protection forests, parks, etc. In other cases it indicates the age of woods which is most favourable for natural regeneration, taking into consideration the conditions of the locality and the silvicultural system under which the forest is managed. In the latter case it cannot be lower in high forest than the age when the trees commence to produce good seed in sufficient quantity, nor as high as the age when the production of good seed has ceased, the best period being that about the end of the principal height growth.

In the case of coppice woods, the rotation must be below the age at which the trees cease to produce good healthy shoots when cut over.

6. The Choice of Rotation in Practical Forestry.

The choice of rotation, or the age at which a wood is to be cut over, is, as already stated, one of the most important questions in practical forestry. Many and various are the arguments which have been advanced in favour of one or the other rotation. On one side, it is asserted that the financial aspect should decide the choice of rotation, since forests represent capital which should yield an adequate interest. On the other side, it is said that the general usefulness of the forests should be the deciding factor, since other considerations are of more importance to the community than high interest, and more especially so in the case of State forests. The latter argument introduces a difference between private and public forests. In the author's view, the question should be governed by the objects which the proprietor desires to realise, whether the forests belong to private persons or to the State. The former will, in the majority of cases, be

guided by financial considerations, though not in all. The State, while not ignoring the financial aspect, must consider other demands in the interest of the community as a whole. For instance, protection forests must generally be managed under high rotations ; the same holds good in growing timber for ship construction ; where land is scarce the rotation of the highest volume production might be indicated ; in other cases, where small dimensions are wanted for important industries, low rotations may be adopted ; special rotations may be necessary where an adequate supply of forest produce is essential to safeguard the country against a timber famine or other emergency, etc.

Whatever the desired rotation may be, the proprietor should know what financial sacrifice its adoption involves, in case it differs from the financial rotation. Hence, the general procedure in fixing the rotation may be described as follows :—

(1.) The proprietor should define the objects at which he is aiming, and especially the class of timber which he desires to produce. The forester should then indicate the rotation under which these objects can be realised in the most economic manner.

(2.) The forester should then calculate the financial results of that rotation, and also of the financial rotation. The difference in the financial results gives the financial loss involved in deviating from the financial rotation.

(3.) In the case of the clear cutting system, and especially under short rotations, the forester should draw special attention to the injurious effects which may be produced by repeated exposure of the locality to atmospheric influences.

With such information before him, the proprietor can give his final decision, whether he be a private person or the State.

The third point given above is of paramount importance when the management aims at a sustained yield. However tempting the clear cutting with subsequent planting or sowing may be, it has more and more been recognised of late years that, except under specially favourable climatic conditions, frequent exposure of the locality leads in the long run to a reduction of the yield capacity of the locality, especially where light-demanding, thin-

crowned, or shallow-rooted species are cultivated in pure woods. In such cases the rotation should not be short, or, at any rate, an admixture of a soil-improving species should be given, either at once or by under-planting at an early age.

The above method of determining the rotation refers to fairly even-aged woods. Its principal usefulness consists in bringing order into the management, and in indicating the time during which the forester should go round the whole area of a working section. In uneven-aged woods, such as the selection forest, the standards in coppice with standards, and irregular forests generally, it is almost impossible to fix an average rotation with any degree of accuracy. In such cases, the ripeness of the individual trees is determined by their reaching the size desired by the objects of management and by the proportion of trees in the several size classes.

CHAPTER III.

THE NORMAL AGE CLASSES.

When, under the system of working for a sustained annual yield, the rotation has been fixed, it is necessary that, year after year, or period after period, the required mature woods are forthcoming, so that the calculated annual yield may be obtained. This involves the establishment of a normal series of age gradations. By that term is understood a series of age gradations or classes so arranged that at all times when cuttings are to be made mature woods of the normal age are available, and so situated that no obstacles to their cutting exist. This means that the age classes or gradations must each be of the proper extent, and that they are properly grouped and distributed over the forest.

If a forest is to be managed according to the system of a sustained annual yield and the clear cutting system, it must contain a series of age gradations equal to the number of years in the rotation; the oldest age gradation must, immediately before cutting, have the age of the rotation, the youngest must be one year old, with a difference of one year in the age of every two gradations.

If the annual returns are to be equal in volume, and the quality of the locality is the same throughout, then all age gradations must be of the same extent; if different qualities occur, the areas of the coupes must be in inverse proportion to the quality of the locality. A series of age gradations so arranged is called *a normal working section.* This subject will again be dealt with further on. For the present it is assumed that the quality of locality is the same throughout.

Frequently, a number of age gradations are thrown together into an age class. The following questions thus arise :—

(1.) What is the area to be cut annually under the different methods of treatment ?

(2.) What is the size of the age classes ?

(3.) How should the age classes be distributed over the forest ?

1. The Annual Coupe, or the Area to be Cut Annually.

This differs according to the method of treatment.

a. Coppice and Coppice with Standards.

The annual coupe is determined by dividing the total area of the forest, or working section, by the number of years in the rotation under which the coppice is worked.

Let total area $= A$, and the rotation of the coppice $= r$, then the annual cutting area $c = \frac{A}{r}$. This holds good for the coppice with standards system, because the annual cutting area is governed by the coppice only.

b. Clear Cutting in High Forest.

Here again :

$$c = \frac{A}{r},$$

if each clearing is at once re-stocked. It frequently happens, however, that the cleared coupes lie fallow for one or more, say s years ; in that case :

$$c = \frac{A}{r + s},$$

so that the forest consists, immediately before cutting, of a series of age gradations from 1 to r years old and s blanks, or altogether $r + s$ coupes.

c. The Shelterwood Compartment or Uniform System.

Under this system, the regeneration of each coupe extends over a number of years, say m; hence, it is necessary to throw m annual coupes together into a regeneration coupe, the crop on which, by gradual cuttings, is led over in the course of m years into a young wood. The size of the regeneration coupe is, therefore, $= \frac{A}{r} \times m$.

In this case, the first of the successive cuttings towards regeneration may be made—

Either in the year r, so that the trees removed at the end of the regeneration period would be $r + m$ years old, and the mean age $r + \frac{m}{2}$ years; in other words, the procedure would lead to a raising of the rotation from r to $r + \frac{m}{2}$ years;

Or, the first cutting may be made in the year $r - \frac{m}{2}$ and the last in the year $r + \frac{m}{2}$, so that the mean final age comes to r years.

In this chapter the latter is assumed.

d. The Selection System.

Strictly speaking, the annual coupe is equal to the total area of the forest. For convenience' sake, however, the cuttings of each year are restricted to a portion of the area, so that it takes a number of years to go round the forest, and before cuttings are again made on the same area. If that number is l, then—

$$\text{Annual cutting area} = \frac{A}{l}.$$

Example.—In the beech forests of Buckinghamshire, which are worked under the selection system, it is usual to go round once in

seven years ; in that case the annual cutting area would be equal to $\frac{A}{7}$. In other cases, as in the Indian Sāl and teak forests, l is longer, generally from 15 to 40 years.

2. Size of the Age Classes.

In forests of some extent which are worked under a high rotation, and especially those regenerated naturally, it is, as a rule, impracticable to separate the annual cutting areas, so that a regular series of age gradations, differing by one year in age throughout, exists. In these cases, it is necessary to be satisfied

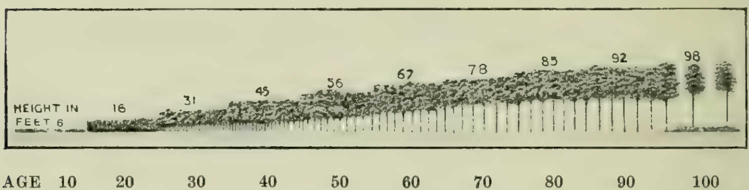


Fig. 46.—A Normal Series of Age Classes, treated under the Uniform System.

with larger groups, that is to say, to join a number of age gradations into an " age class." The normal size of such an age class depends on the area of the annual coupe and the number of such coupes thrown together.

If a class contains n gradations, its area would be $= n \times c$.

The number of age classes $= \frac{r}{n}$ is variable.

Another way is to fix the number of age classes ; in that case n is variable, but this procedure is not to be recommended, as it is likely to lead to confusion.

It is usual to take for n a round number, say 10, 20, or even 30 ; in coppice woods, n is usually taken as $= 5$. The age classes are numbered. It is best to call the youngest I., the next youngest II., and so on ; for instance, if $n = 20$—

First age class I., contains all woods up to 20 years old.
Second ,, II., ,, ,, from 21 to 40 years old.
Third ,, III., ,, ,, ,, 41 to 60 ,,
And so on.

In this way, the number of the age class indicates directly the limit of ages of the woods contained in it. The reverse method, of calling the oldest age class I., the next oldest II., etc., is less desirable, but unfortunately it has been largely adopted.

The number of years included in an age class is called a "period," and the area dealt with in the course of a period is called a "Periodic Coupe" (French: "Affectation").

The area of the age classes under the several methods of treatment will be as follows :—

a. Clear Cutting in High Forest.

The area of each age class, C, in a normal state, is—

$$C = n \times c = n \times \frac{A}{r}, \text{ or } C = n \times \frac{A}{r+s},$$

according as to whether each clearing is at once re-stocked, or allowed to lie fallow for s years.

Example.—Let area $A = 1{,}000$ acres, rotation $r = 100$ years, $s = 0$ years, $n = 20$ years.
Then,

$$\text{Annual age gradation} = \frac{A}{r} = \frac{1{,}000}{100} = 10 \text{ acres};$$

and the age classes :—

C_1 (1— 20 years old woods)	$= c \times n = 10 \times 20 =$	200 acres.
C_2 (21— 40 ,, ,,)	$=$,, $=$,, $=$	200 ,,
C_3 (41— 60 ,, ,,)	$=$,, $=$,, $=$	200 ,,
C_4 (61— 80 ,, ,,)	$=$,, $=$,, $=$	200 ,,
C_5 (81—100 ,, ,,)	$=$,, $=$,, $=$	200 ,,
	$A =$	1,000 acres.

b. Shelterwood Compartment System.

As already explained, under this system the old crop is gradually led over into a young wood in the course of a number of years, which may be indicated by m. There is always an area under regeneration which contains a certain number of old and young trees, called the Regeneration Class $= C_v$. It progresses gradually through the whole working section, and is found in its original position at the beginning of the second rotation.

The appended illustration 47 further explains this process in the case of $m = n$.

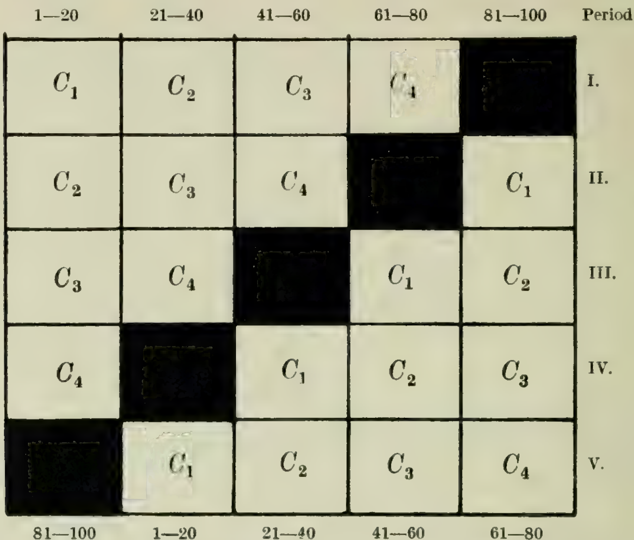


Fig. 47.—Position of the Regeneration Area during the Five Periods.

As the length of regeneration differs much according to local conditions at the time, it is impossible to define its duration accurately, and least of all can it be placed equal to n, the number of years in the period. Under these circumstances, the arrangement of age classes at the commencement of the rotation can be indicated only approximately, somewhat in the following manner :—

Cuttings in the oldest age class commence when the crop is $r - \frac{m}{2}$ years old, and the last cutting when the crop is $r + \frac{m}{2}$ years old ; in that case the average age should be r years ; the annual cutting area should be $= \frac{A}{r}$ and the area of the regeneration class $C_v = \frac{A}{r} \times m$. The latter contains areas as yet blank, young trees from 1 to m years old, and the remaining old trees up to $r + \frac{m}{2}$ years old. It forms part of the oldest age class. It may happen

that $m = n$, in which case the oldest age class is identical with the regeneration class C_v. Again, it may happen that $m > n$, in which case C_v contains not only the oldest age class, but also a portion, if not the whole, of the second oldest age class. Hence, the size of the several age classes may be expressed as follows :—

(1.) $m < n$.

$$C_1 = \frac{A}{r} \times n\,;\ C_2 = \frac{A}{r} \times n\,;\ C_3 = \frac{A}{r} \times n\,;\ C_4 = \frac{A}{r} \times n\,;$$

$$C_5 = \frac{A}{r} \times (n - m), \text{ and } C_v = \frac{A}{r} \times m.$$

Example :—

Let $m = 15$; $n = 20$; $r = 100$; $A = 1{,}000$ acres ; Annual coupe = 10 acres.

$C_1 = 10 \times 20 = 200$; $C_2 = 10 \times 20 = 200$; $C_3 = 10 \times 20 = 200$. $C_4 = 10 \times 20 = 200$; $C_5 = 10 \times 5 = 50$; $C_v = 10 \times 15 = 150$ acres. Total area = 1,000 acres.

(2.) $m = n$.

Example.—Let both be = 20.

C_1, C_2, C_3, C_4, each 200 acres, total = 800 acres ; $C_5 = 0$; $C_v = 10 \times 20 = 200$. Total area = 800 + 200 = 1,000.

(3.) $m > n$.

Example.—Let $m = 30$.

$C_1 = C_2 = C_3 = 200$ each = 600 ; $C_4 = 10 \times 10 = 100$; $C_5 = 0$; $C_v = 10 \times 30 = 300$. Total = 600 + 100 + 300 = 1,000 acres.

It is obvious that in the case of the shelterwood system with natural regeneration the above allotment is only of an ideal character, because the actual duration of the regeneration is so uncertain. The regeneration class, the oldest and the youngest classes are subject to modifications between themselves, so that they cannot easily be separated the one from the other ; hence, they are best thrown together. The important point in that case is that the middle-aged classes are of the proper size. The allotment may then be represented as follows :—

$C_2 = C_3 = C_4 = 200$ each together = 600 acres ;
$C_5 + C_1 = C_v = 1000 - 600$ = 400 „

Total = 1,000 acres.

Or, if regeneration extends over a still longer period :—

$$C_3 = C_4 = 200 \text{ each, together} \quad = \quad 400 \text{ acres};$$
$$C_5 + C_1 + C_2 = C_v = 1000 - 400 = \quad 600 \quad ,,$$
$$\text{Total} = 1{,}000 \text{ acres.}$$

This system has been practised for 100 years in parts of the Black Forest, as well as elsewhere, in Germany (*Femelschlag-betrieb*). A somewhat modified form of it has of recent years been developed in France, where it goes by the name of *Quartier Bleu*, owing to the areas under regeneration being painted blue on the French forest maps. All parts of the regeneration area which become fully stocked with young growth are taken out, and joined with the middle-aged areas, while corresponding areas of old woods are moved into the *Quartier Bleu*.

c. Coppice Woods.

As the rotation of coppice woods is short, it is usually possible to mark the annual coupes on the ground, so that the formation of age classes is not necessary. If the latter should be desirable, generally not more than five gradations are thrown together to form an age class. *Example:* Area $= 200$ acres; $r = 20$ years; annual coupe $= 10$ acres; each age class $= 10 \times 5 = 50$ acres, and number of age classes $= 4$.

d. Coppice with Standards.

Here each coupe contains coppice (underwood) and standards (overwood). As far as the underwood is concerned, the arrangement is exactly the same as in the case of simple coppice; the annual age gradation is $= \frac{A}{r}$, and the age class, if any, $= \frac{A}{r} \times n$.

The distribution of the overwood, in its normal condition, is somewhat peculiar, which may usefully be explained here, though it is only of *theoretical* value.

In the first place, it should be remembered that cuttings in both the under- and overwood on the same area must be made at the same time, or rather those in the overwood must be made immediately after the underwood has been cut over, and before the new coppice shoots appear; hence, the rotation R of the

overwood must be a multiple of the rotation r of the underwood, say $R = r \times t$.

In each annual coupe, when cutting comes round to it, a certain portion of the underwood (chiefly seedling trees) is left standing to form the youngest age gradation of the overwood. That portion should occupy an area $= \frac{A}{R}$, assuming that each age gradation of the overwood occupies the same extent of ground. The area occupied by each age class of overwood comes to $= \frac{A}{R} \times r = \frac{A}{t}$.

Assuming now that the youngest overwood class, 1 to r years old, though still forming part of the underwood, is already counted as belonging to the overwood, then there are t overwood classes. The latter are not separated according to area, as in the case of clear cutting or coppice, but t gradations are standing mixed on each annual coupe, so that each of the latter contains $\frac{1}{r}$th part of each overwood class.

Immediately before cutting, the arrangement would be as follows :—

Underwood, Age in Years.	1	2	3	...	...	$r-1$	r
Overwood Age Class C_1 age	1	2	3	...	...	$r-1$	r
,, ,, ,, C_2 ,,	$r+1$	$r+2$	$r+3$	...	...	$2r-1$	$2\times r$
,, ,, ,, C_3 ,,	$2r+1$	$2r+2$	$2r+3$	...	...	$3r-1$	$3\times r$
. . . .							
,, ,, ,, C_r ,,	$(t-1)r+1$	$(t-1)r+2$	$(t-1)r+3$	...	...	$t\times r-1$	$t\times r$

It will be seen that a normal coppice with standards forest must have an overwood which consists of $t \times r = R$ age gradations ranging from 1 year up to R years old.

Example.—A forest of 200 acres, worked under a rotation of 20 years for the underwood and 100 years for the overwood, has $\frac{100}{20} = 5$ overwood classes. On the 10 acres which are about to be cut will be found—

Underwood = 20 years old.
Overwood = 20, 40, 60, 80 and 100 years old.

Fig. 48.—Coppice with Standards. One Coupe.
Rotation of underwood = 20 years. Rotation of overwood = 100 years.
Coppice just cut.

Fig. 49.—Coppice with Standards. One Coupe.
Rotation of underwood = 20 years. Rotation of overwood = 100 years.
Age of coppice, 10 years.

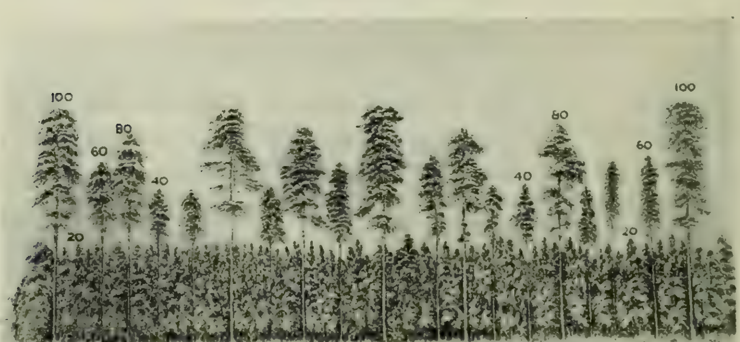


Fig. 50.—Coppice with Standards. One Coupe.
Rotation of underwood = 20 years. Rotation of overwood = 100 years.
Age of coppice 20 years

The next oldest coupe contains—

Underwood = 19 years old
Overwood = 19, 39, 59, 79 and 99 years old.

The youngest coupe contains—

Underwood = 1 year old
Overwood = 1, 21, 41, 61 and 81 years old.

DISTRIBUTION OF THE OVERWOOD IF COPPICE WITH STANDARDS. TWENTY COUPES.

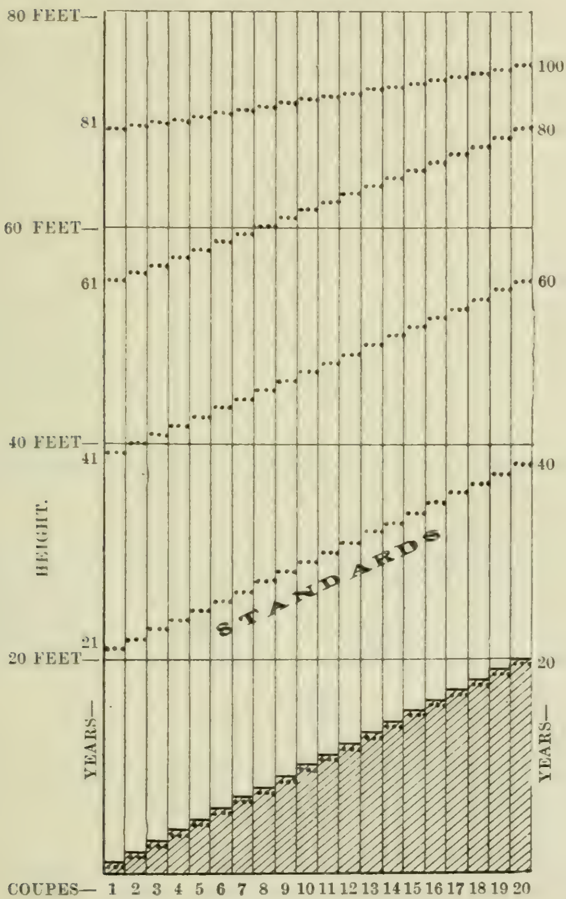


Fig. 51.—(Conventional.)

The figures 48, 49, 50, and 51 illustrate the distribution of the several age gradations over the area.

The area occupied by each overwood class can be determined only by assuming that each gradation occupies an equal extent of ground; hence, the youngest gradation will have most trees and the oldest least. Imagining now that the age classes of the overwood were not intermixed, but that the trees of each class were brought together on separate areas, then the overwood, apart from the coppice, would form an open high forest. Of these woods, the youngest would contain the standards from 1 to r years, the next those from $r + 1$ to $2\,r$ years, and so on. By degrees, the youngest class passes through all the intermediate stages, until it becomes the oldest and is cut over in the course of r years. At each annual cutting, therefore, an equal area must be cut over, on which the new, that is the youngest, gradation is started, either naturally or artificially.

The annual coupe is $c = \frac{A}{r}$ and $A = c \times r$.

The number of overwood classes is $= \frac{R}{r} = t$, hence—

$$R = t \times r.$$

Area of each age class on each annual coupe $= \frac{A}{R} = \frac{A}{t \times r} = \frac{c}{t}$,

or,

$$\frac{200}{100} = \frac{200}{5 \times 20} = \frac{10}{5} = 2 \text{ acres.}$$

As the whole forest consists of r coupes, each overwood class, consisting of r gradations, contains, in a normal forest, $\frac{c}{t} \times r = \frac{A}{t}$ units of area, or $\frac{200}{5} = 40$ acres. This shows that, theoretically, the proportion of the age classes is the same as in high forest, although the distribution is different.

Example.—Data as before.

$A = 200$; $R = 100$; $r = 20$, number of overwood classes $t = 5$.

Normal annual cutting area $c = \frac{A}{r} = \frac{200}{20} = 10$ acres.

On each coupe each age gradation of overwood occupies . . $\left.\right\} \frac{c}{t} = \frac{10}{5} = 2$ acres.

The area and distribution of the several age classes are as follows:—

Coupe No. 20, oldest :

Underwood	=	10 acres	=	20 years old.
Overwood on		2 ,,	=	20 ,, ,,
,, ,,		2 ,,	=	40 ,, ,,
,, ,,		2 ,,	=	60 ,, ,,
,, ,,		2 ,,	=	80 ,, ,,
,, ,,		2 ,,	=	100 ,, ,,

Coupe No. 1, youngest :

Underwood	=	10 acres	=	1 year old.
Overwood on		2 ,,	=	1 ,, ,,
,, ,,		2 ,,	=	21 years ,,
,, ,,		2 ,,	=	41 ,, ,,
,, ,,		2 ,,	=	61 ,, ,,
,, ,,		2 ,,	=	81 ,, ,,

The normal state of the age classes in the case of coppice with standards is of a still more ideal character than in the case of the shelterwood compartment system; it can only serve as a mathematical guide for the treatment of such woods, as it gives some idea of the relative number of trees which should be found in each class or gradation. Each of these should occupy about the same area; hence, the youngest class must contain a large number of trees, which is gradually reduced to a comparatively small number in the oldest age class. The actual proportion in these numbers depends on the species, the quality of the locality and the objects of the proprietor.

e. The Selection Forest.

If the annual cuttings extend over the whole area, then all age classes are, theoretically speaking, represented in all parts of the forest; if, on the other hand, the cuttings pass over the forest in the course of a number of years, say l, then the age classes will, to some extent, gradually become located similarly to the distribution of the overwood in a coppice with standards forest. The number of age classes will, theoretically, be equal to $\frac{r}{l}$.

Example.—Let $A = 1{,}000$ acres; $r = 100$; $l = 20$; then each annual cutting area $= \frac{A}{l} = \frac{1{,}000}{20} = 50$ acres, and the distribution would approximately be as follows:—

Coupe No. 1 (*youngest*).	*Coupe No.* 2.
1 year old trees = 10 acres	2 year old trees = 10 acres
21 ,, ,, ,, = 10 ,,	22 ,, ,, ,, = 10 ,,
41 ,, ,, ,, = 10 ,,	42 ,, ,, ,, = 10 ,,
61 ,, ,, ,, = 10 ,,	62 ,, ,, ,, = 10 ,,
81 ,, ,, ,, = 10 ,,	82 ,, ,, ,, = 10 ,,
Total = 50 acres	Total = 50 acres

Coupe. No. 19.	*Coupe No.* 20 (*oldest*).
19 years old trees = 10 acres	20 years old trees = 10 acres
39 ,, ,, ,, = 10 ,,	40 ,, ,, ,, = 10 ,,
59 ,, ,, ,, = 10 ,,	60 ,, ,, ,, = 10 ,,
79 ,, ,, ,, = 10 ,,	80 ,, ,, ,, = 10 ,,
99 ,, ,, ,, = 10 ,,	100 ,, ,, ,, = 10 ,,
Total = 50 acres	Total = 50 acres

Each year the 100 years old trees in the oldest coupe would be cut, and they should cover an area equal to one-fifth of the coupe, equal to 10 acres, thus cutting the whole area of the forest once in 100 years. It is needless to add that such regularity is never reached in practical forest management.

Regeneration of the cut spots may occur in the following year, but, as a rule, it occurs gradually, extending over several years, unless planting or artificial sowing is done.

Details of the management of selection forests will be found in Part IV.

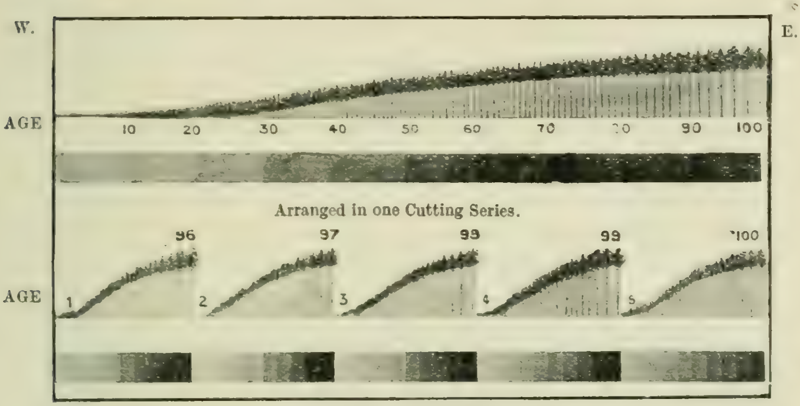
3. Distribution of the Age Classes over the Forest.

By a normal distribution of the age classes is understood that which admits of a proper succession of cuttings, so that each wood is cut at the proper age, and that the other woods are protected against external dangers, in so far as this can be done by careful management.

It has already been explained that every deviation from the normal age interferes with the full realisation of the objects of management; hence, the age classes should be so distributed that no such deviations are called for. Of special importance, in

this respect are threatening dangers, such as damage by strong winds, dry air currents, drought, danger from frost, fire, insects, etc., and, in some cases, considerations for a successful regeneration.

Strong winds or gales are a most important consideration. Their prevailing direction must be ascertained, and cuttings should generally proceed against it. Assuming that the strong winds blow from the west, the youngest age class should, at the commencement, be situated at that side and the oldest on the east, so that the cuttings proceed gradually from east to west. (See



Arranged in five Cutting Series.

Fig. 52.—A Normal Series of Age Gradations, treated under the Clear Cutting System.

diagram, Fig. 52, upper part.) In this case, the younger age classes gradually break the force of the wind, while the youngest (in the diagram) will grow up exposed to the strong wind; its edge trees will develop strong root systems, and the wood will then be able to resist the force of the wind when it grows up to become the oldest age gradation. Nevertheless, shelter belts may be required in addition.

In determining the prevailing wind direction, it must not be overlooked that it is frequently changed in hilly and mountainous tracts according to the direction of the valleys and hill ranges.

In cases where clear cutting, followed by artificial regeneration, is practised, protection of the cleared areas against the sun is frequently essential. As a consequence, the direction of cutting

may have to be changed into north to south. The breadth of the cleared area should not exceed the height of the adjoining old wood, but it may be of any length. To increase the effect of the old wood, the edge is sometimes given a zig-zag shape, a subject dealt with in Part IV.

Dry winds frequently blow from a direction differing from that of strong winds; in that case, the forester must decide which is the more important consideration of the two, and determine the cutting direction accordingly. Frequently, the seeds of trees fall under the effect of a dry wind, so that the cleared areas which are to be naturally regenerated must be situated to the leeward of the seed-bearing trees, as, for instance, under the strip system with regeneration by seed fallen from trees standing on the adjoining area.

Drought is a formidable enemy to successful forest management in all cases where the amount or distribution of the rainfall over the seasons of the year is unfavourable. In some countries droughts occur practically every year, especially in spring and early summer. In such cases the forester must strive to reduce their effect by avoiding large clearances in one place, or, better still, by effecting regeneration under shelterwoods. This matter is of paramount importance in the choice of the system of management.

Large clearings in one place are generally objectionable, because the soil is liable to dry up, and damage by frost is likely to occur; hence, in extensive forests the area to be cut annually may have to be divided into a number of small coupes situated in different parts of the forest.

Insects and fire are likely to be most injurious when several cuttings made in consecutive years adjoin each other, because the former wander from one coupe to the next, while fire spreads more rapidly in continuous young woods than if they are interrupted by older woods.

These circumstances demand in many cases, and especially where clear cutting is practised in coniferous woods, that a second cutting should not be made in any locality until the former coupe has been successfully restocked. This leads to the splitting up of a working section, or a series of age gradations, into several subdivisions which are called *Cutting Series.* Supposing, in a forest

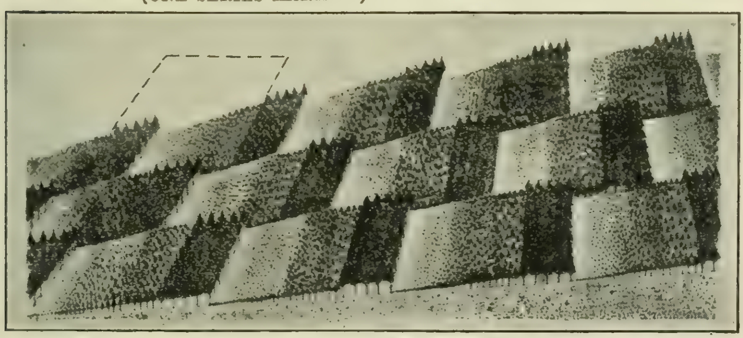
worked under a rotation of 100 years, it was considered necessary not to cut in the locality adjoining a previous cutting except after a lapse of five years, the series of 100 age gradations would be divided into five cutting series, of which each would comprise 20 coupes. (See Fig. 52, lower part.)

Cutting Series A	would comprise the coupes now	100, 95 .. 10, 5,	years old.
,, ,, B	,, ,, ,, ,,	99, 94 .. 9, 4,	,, ,,
,, ,, C	,, ,, ,, ,,	98, 93 .. 8, 3,	,, ,,
,, ,, D	,, ,, ,, ,,	97, 92 .. 7, 2,	,, ,,
,, ,, E	,, ,, ,, ,,	96, 91 .. 6, 1,	,, ,,

As a general rule, a careful distribution of the age classes over the area of the forest is of special importance in the case of species which are easily thrown by wind, liable to attacks by insects, to danger from fire or frost, and also those which are difficult to regenerate naturally. In all these cases, a distribution must be aimed at which allows the cutting of each wood when mature,

VIEW OF A FOREST DIVIDED INTO CUTTING SERIES WORKED UNDER THE STRIP SYSTEM.

(ONE SERIES MARKED.)



PREVAILING WIND DIRECTION. ⟶ CUTTING DIRECTION. ⟵

Fig. 53.

without thereby endangering on the one hand the adjoining woods and on the other the successful regeneration of the cleared area.

The above considerations must specially guide the forester in the case of forests worked under the systems of clear cutting, and also of the shelterwood compartment system. They are of less importance in coppice, coppice with standards, and selection

forests ; but even here the cutting direction should be carefully determined.

At the same time, the forester should not go to extremes, as there is something to be said on both sides.

Reasons for adjoining the annual coupes are :—

(1.) Best security against damage by storms.

(2.) Reduction to a minimum of damage by overhanging trees.

(3.) Production of a larger percentage of high-class timber.

(4.) Reduction of the cost of transport of forest produce.

Reasons for the establishment of cutting series are :—

(1.) Reduction of danger through fire and insects.

(2.) Better protection of young woods against raw or dry winds, frost, and diseases.

(3.) Greater freedom in selecting the areas to be cut over at any time. To illustrate this point, Fig. 53 is added, which shows a bird's-eye view of a large number of cutting series.

CHAPTER IV.

THE NORMAL GROWING STOCK.

It has been stated at page 170 that by the normal growing stock is understood that present in a forest which has a normal series of age gradations or classes and a normal increment. This being so, the forester need only see that the age classes and increment are normal, and the normal growing stock will be present as a natural consequence.

It happens, however, that, as far as volume is concerned, the normal growing stock may be present if neither the normal age classes nor increment have been established ; for instance, if the deficit in one age class is made good by a surplus in another. If, in such a case, an annually equal quantity of wood were cut, it would lead to a deviation from the normal final age and probably to loss. Indeed, the normal growing stock according to quantity might be present if the whole forest consisted of only one uniform age class of about half the normal final age. In that case, no ripe wood at all would be found in the forest, and final cuttings would have to be suspended for a considerable number of years.

In these circumstances, the normal growing stock measured by a certain number of cubic feet is of subordinate importance in determining the yield of a forest, and yet it is useful to look at its determination for the following two reasons :—

(1.) Because the yield, taken out of a forest in the course of a rotation, consists partly of the growing stock which was present at the beginning of the rotation and partly of increment added to that growing stock during the rotation.

(2.) Because several methods of treatment base the calculation of the yield upon the difference between the normal and real growing stock.

The amount of the normal growing stock depends on the length

of the rotation; the higher the latter, the greater is the former for one and the same area and quality class.

In calculating the normal growing stock, only the principal part of the woods, which gives the final yield, is taken into account, because, as previously explained, the determination of a sustained yield is, in the first place, based upon the final yield.

The normal growing stock can be looked at from the volumetric or the financial point of view.

SECTION I.—CALCULATION OF THE VOLUME OF THE NORMAL GROWING STOCK.

1. Clear Cutting in High Forest.

It has already been explained on page 147 that, under the system of clear cutting and a sustained yield, the normal growing stock consists of a series of age gradations ranging from 0 years to $r - 1$ years old, with a difference of one year between the ages of every two succeeding age gradations; this occurs in a temperate climate in spring, before the annual increment has been laid on.

a. Calculation from Yield Tables.

If a yield table is available for a forest which gives the produce standing in it from year to year, the normal growing stock is equal to the sum of the major part of all the growing stocks given in that table from the year 0 to the year $r - 1$; that sum would represent the normal growing stock in spring of r units of area.

If the yield table, and this is generally the case, gives the volumes only from period to period, say for every n years, then the approximate amount of the normal growing stock can be calculated by assuming that the volumes rise within each period of n years according to an arithmetical series—that is to say, by adding the same number of cubic feet each year.

Let the rotation be r, the interval between every two positions in the yield table n, and the volumes for these positions in the

Years	o	n	$2n$	$3n$		$r - n$	r
Volumes	V_o	V_n	V_{2n}	V_{3n}	. .	V_{r-n}	V_r, then:

Volume of gradation 0 to $n = (V_o + V_n) \times \frac{n+1}{2}$

,, ,, n to $2n = (V_n + V_{2n}) \times \frac{n+1}{2}$

Volume of gradation $2n$ to $3n = (V_{2n} + V_{3n}) \times \frac{n+1}{2}$

$\vdots$

,, ,, $r - n$ to $r = (V_{r-n} + V_r) \times \frac{n+1}{2}$.

The sum of these amounts comes to :—

$$\frac{n+1}{2}\Big(V_o + 2V_n + 2V_{2n} + 2V_{3n} + \ldots + 2V_{r-n} + V_r\Big)$$

$$= \Big(n+1\Big)\ \Big(V_n + V_{2n} + V_{3n} + \ldots ; + V_{r-n} + \frac{V_r}{2}\Big).$$

It should be noted that V_n, V_{2n}, V_{3n}, . . . V_{r-n} have been twice introduced in the above calculation; these values must be deducted to make the calculation correct, leaving the true value at :—

$$\text{Normal growing stock} = \Big(n+1\Big)\ \Big(V_n + V_{2n} + V_{3n} + \ldots + V_{r-n} + \frac{V_r}{2}\Big) - \Big(V_n + V_{2n} + V_{3n} + \ldots V_{r-n}\Big),$$

which, after reduction, gives :—

$$\text{Normal growing stock} = n \times \Big(V_n + V_{2n} + V_{3n} + \ldots + V_{r-n} + \frac{V_r}{2}\Big) + \frac{V_r}{2}.$$

This is the value for autumn. To obtain the value for spring, the volume of the oldest age gradation V_r must be deducted, giving—

$$\text{Normal growing stock for spring} = n\Big(V_n + V_{2n} + V_{3n} + \ldots + V_{r-n} + \frac{V_r}{2}\Big) - \frac{V_r}{2}.$$

The average of the two values gives the growing stock for the middle of the growing season, say midsummer :—

$$\text{Normal growing stock for summer} = n\left(V_n + V_{2n} + V_{3n} - \ldots + V_{r-n} + \frac{V_r}{2}\right).$$

Example.—Given an area of 80 acres worked under a rotation of 80 years for larch to which the yield table for larch III. quality applies, the normal growing stock would amount to :—

Spring $^{80}G_{normal} = 10\ (150 + 560 + 1{,}460 + 2{,}290 + 2{,}910 + 3{,}440 + 3{,}910 + 2{,}150) - 2{,}150$
$= 10 \times 16{,}870 - 2{,}150 = 166{,}550$ cubic feet.
Autumn $^{80}G_{normal} = 10 \times 16{,}870 + 2{,}150 = 170{,}850$ „ „
Summer $^{80}G_{normal} = 10 \times 16{,}870 = 168{,}700$ „ „

As the differences between the three amounts are small, foresters are in the habit of using the somewhat shorter formula for summer.

Assuming that the 80 acres were worked under a rotation of 60 years, $^{60}G_n = 10\ (150 + 560 + 1{,}460 + 2{,}290 + 2{,}910 + 1{,}720) - 1{,}720 = 89{,}180$. This is the G_n for 60 acres. As the total area is 80 acres, the G_n for 80 acres is obtained by multiplying 89,190 by $\frac{80}{60} = 118{,}907$ cubic feet. Hence, if the forest, hitherto worked under a rotation of 80 years, is in future to be worked under one of 60 years, the normal G_n would have to be reduced by $166{,}550 - 118{,}907 = 47{,}643$ cubic feet. That amount can be taken out of the forest in addition to the annual increment; in the reverse case 47,653 cubic feet would have to accumulate in the forest to bring up the $^{80}G_n$ to its proper amount.

b. Calculation with the Mean Annual Increment.

A shorter, but less accurate, method of calculating the normal growing stock is based upon the assumption that the normal final yield is produced in annually equal instalments throughout the rotation; in other words, that the growing stock of the several age gradations forms an arithmetical series. If one year's increment is equal to i, the growing stock of succeeding age gradations would be :—

Year . . $= 1 \quad 2 \quad 3 \quad \ldots \quad r{-}1 \quad r$
Growing stock . $= i,\ i \times 2,\ i \times 3, \ldots (r{-}1) \times i,\ r \times i$

and $$G_n = (i + r\,i) \times \frac{r}{2} = \frac{r\,i}{2} + r\,i \times \frac{r}{2}.$$

As $r \times i$ represents the growing stock of the oldest age gradation, and is also equal to the total increment, I, laid on by all gradations during one year, the above formula may be written thus :—

$$G_n, \text{ autumn} = \frac{I \times r}{2} + \frac{I}{2}; \text{ Spring} = \frac{I \times r}{2} - \frac{I}{2}; \text{ Summer} = \frac{I \times r}{2}.$$

The growing stock calculated by this formula (for spring) is larger than that calculated from yield tables for short, and smaller for long rotations, as the following table will show :—

NORMAL GROWING STOCK (SPRING) OF SCOTS PINE I. QUALITY.

Rotation.	From Yield Tables.	From Mean Increment.	Excess from M.I.
30	18,780	28,130	+ 9,350
40	43,440	60,790	+ 17,350
50	79,050	100,450	+ 21,400
60	123,380	142,780	+ 19,400
70	174,480	187,680	+ 13,200
80	231,040	233,840	+ 2,800
90	292,175	282,575	− 9,600
100	357,340	332,640	− 24,700

2. THE SHELTERWOOD COMPARTMENT, OR UNIFORM, SYSTEM.

The normal growing stock, is theoretically, the same as for the clear cutting system, provided that the regeneration cuttings are so arranged that one-half are made before the year r and the other half after it, that the timber in the regeneration class is removed in annually equal quantities, and that regeneration takes place in the middle of the regeneration period. In reality, this occurs only rarely, but the deviations compensate each other in the long run.

Another point is that the forester has, in the majority of cases, to deal with two or more quality classes. In such cases, he must deal with each quality class separately, or proceed with a combined system somewhat on the lines of the following example :—

Example.—Let there be 100 acres stocked with Scots pine, of which 40 acres are I. class quality and 60 acres II. class. The wood is divided into five age classes of 20 acres each, but parts of the two quality classes

are found in each age class. Utilizing the data for Scots pine I. and II. quality (page 126) the calculation would be as follows :—

Age Class.	Mean Age.	I. Quality Class.			II. Quality Class.			Grand Total.
		Area.	Volume per Acre.	Total.	Area.	Volume per Acre.	Total.	
I.	10	40	200	8,000	60	100	6,000	$\frac{14,000}{5}$ = 2,800
II.	30	40	1,940	77,600	60	1,300	78,000	$\frac{155,600}{5}$ = 31,120
III.	50	40	4,100	164,000	60	3,450	207,000	$\frac{371,000}{5}$ = 74,200
IV.	70	40	5,440	217,600	60	4,880	292,800	$\frac{510,400}{5}$ = 102,080
V.	90	40	6,350	254,600	60	5,880	352,800	$\frac{607,400}{5}$ = 121,480
								331,680

Total normal growing stock = 331,680 cubic feet.
Average per acre = 3,317 „

3. Coppice and Coppice with Standards.

The calculation for simple coppice is the same as that for clear cutting in high forest.

For coppice with standards forest, the calculation must be made separately for underwood and standards, and the results added. The amount of the former depends chiefly on the number of standards per acre. If the latter are numerous, the normal growing stock of the coppice is frequently so small that it can be neglected.

The calculation of the normal growing stock of the overwood is a complicated and uncertain operation, and chiefly of theoretical value, as it gives an idea of the proportions which ought to exist between the several age classes. The method of calculation may proceed on the following lines : In accordance with the objects of the proprietor, the normal number of standards in each of the r, $2\,r$, $3\,r$ . . . old age classes, and the volumes of the average standards in each of the classes are ascertained. Assuming that the trees increase in volume in each class according to an arithmetical series, it is possible to interpolate the volume of the trees $r+1$, $2\,r+1$, . . . years old. Omitting the future standards which

as yet form part of the coppice, the normal volume of the first age class above the age of r would be $\frac{r}{2}\left(V_{r+1} + V_{2r}\right)$, the next class $\frac{r}{2}\left(V_{2r+1} + V_{3r}\right)$ and so on, and the normal growing stock

$$G_n = \frac{r}{2}\left(V_{r+1} + V_{2r} + V_{2r+1} + V_{3r} + \ldots + V_{nr}\right).$$

Example.—Area of a coppice with standards wood = 20 acres.
Rotation of coppice = 20 years ; of overwood = 100 years.
Number of overwood classes = $\frac{100}{20}$ = 5. Area of each coupe = 1 acre.

Age of Gradations.	Number of Standards in Gradation.	Mean Volume per Tree, Cubic Feet.	Total Volume of Gradation.
21	40	1	40
40	40	5	200
41	26	5·5	143
60	26	15	390
61	16	15·75	252
80	16	30	480
81	8	31	248
100	8	50	400

$$G_n = \left(40 + 200 + 143 + 390 + 252 + 480 + 248 + 400\right) \times \frac{20}{2}$$

$G_n = 2153 \times 10 = 21{,}530$. Average per acre = 1,076 cubic feet.

The above volume should be present immediately before the annual cutting is made. From it should be deducted the volume annually removed, which consists of the following quantities :—

Annual Yield :	14 trees	40 years old,	each 5 cubic feet	=	70 cubic feet.
	10 ,,	60 ,, ,,	,, 15 ,, ,,	=	150 ,, ,,
	8 ,,	80 ,, ,,	,, 30 ,, ,,	=	240 ,, ,,
	8 ,,	100 ,, ,,	,, 50 ,, ,,	=	400 ,, ,,

Total annual yield = 860 cubic feet.

Hence, normal annual growing stock before cutting = 20,670 cubic feet.

It may be added that the annual increment in this case is :

Annual increment $I = 40 \times 5 + 26 \times 10 + 16 \times 15 + 8 \times 20 = 860$ cubic feet, which is equal to the annual yield.

4. The Selection Forest.

As all age gradations are represented in all parts of the forest, it is difficult to give a precise expression of the normal growing stock. Theoretically speaking, in a normal selection forest all age

gradations should be represented in the same proportion as in the system of clear cutting in high forest ; hence the volume should be the same in both cases. In practice, however, this is rarely, if ever, the case. As a general rule, the older age classes occupy more area than the younger ones. In these circumstances, all that can be said is that the age gradations should be represented in such manner and proportion that the returns meet the objects of the proprietor, whether he aims at the production of trees of certain sizes or at other classes of produce.

In Part IV., when dealing with the determination of the yield of selection forests, the subject will be further explained.

SECTION II.—THE FINANCIAL ASPECT OF THE NORMAL GROWING STOCK.

The method of calculating the financial value of the normal growing stock is dealt with in Forest Valuation. Here it suffices to state that it is equal to the capitalised annual net receipts, minus the value of the soil, as represented by the formula :—

$$_{Normal}G_n = \frac{Y_r + T_a + T_b + \ldots + T_q - (c + r \times e)}{\cdot 0p} - r \times S,$$

where p represents the mean annual forest per cent. It depends on the value of S introduced whether the formula represents the cost or expectation value of the growing stock.

CHAPTER V.

THE NORMAL YIELD.

By the normal yield is understood that which a normal forest can permanently give. It can be determined for one year or for a number of years; in the latter case it is called the "periodic yield."

The normal yield consists of the final and intermediate (thinnings) returns. The yield of wood is generally subdivided into various classes, such as timber, cord-wood, faggots, root-wood, etc. In order to bring them into the account, all the different classes are reduced to one common standard, that is "the solid cubic foot." The yield can be determined by area, by volume, or by its financial value. How this is done will be shown in Part IV. of this book. Here only a few remarks as regards the normal yield will be recorded.

1. Determination by Area and Volume.

a. Clear Cutting in High Forest.

The normal final yield is equal to the volume which stands on the oldest age gradation of a normal series of gradations. The normal annual cutting area is $= \frac{A}{r}$ or $= \frac{A}{r + s}$, according as to whether the cleared area is at once restocked or allowed to lie fallow for s years. The volume standing on this area will give the normal final annual yield, provided the stocking is normal. The periodic normal coupe for n years is $= \frac{A}{r} \times n$, or $= \frac{A}{r + s} \times n$. In either case, the thinnings have to be added.

Example.—A Scots pine forest of first-class quality has an area of 100 acres, and is managed under a rotation of 100 years; hence, the normal annual cutting area will be equal to 1 acre; it will be restocked as soon as

cleared. According to the yield table on page 126, the annual yield will consist of :—

(1.) The final yield, being the stand on the 100 years old gradation . . . . 6,930 cubic feet.
(2.) The yield of thinnings from the years 20 to 90 = 2,765 „ „

Total normal yield = 9,695 cubic feet.
Mean annual yield per acre = 97 cubic feet.

The normal yield differs largely according to the quality of the locality and species, as the following data will show: for a rotation of 80 years in all cases, in cubic feet per acre :—

		Quality Classes.				
		I.	II.	III.	IV.	V.
Clear cutting	Larch in Britain	115	96	77	61	44
	Spruce in Britain ..	175	146	117	92	72
	Scots pine in Scotland ..	101	86	67	..	..
Shelterwood system	Silver fir in Germany ..	170	..	106	..	61
	Beech in Germany ..	116	..	68	..	31
	Oak in Germany	109	..	72	..	39

The normal annual yield must be equal to the total annual increment. To cut less than that amount leads to a higher rotation, and *vice versâ*. It will also lead to a reduced yield, if the rotation is fixed at an age beyond that at which the mean annual increment culminates.

b. The Shelterwood Compartment, or Uniform, System.

The calculation of the normal yield is the same as in the case of the clear cutting system, provided that the rotation r is maintained; in other words, that cuttings are commenced in the year $r - \frac{m}{2}$ years and an equal volume is removed annually during the regeneration period of m years.

c. The Selection Forest.

The determination of the yield of selection forests will be dealt with in Part IV. That of the normal yield is only of theoretical interest. If all trees which are cut in one year were brought together on a portion of the area, the latter would be equal to $\frac{A}{r}$,

so that the normal yield should be equal to that of the clear cutting or uniform systems. Such regularity is, however, never reached in the selection forest, nor in many cases desired.

The case may be considered from a different point of view : As only a part of a selection forest is dealt with in each year, say $= \frac{A}{l}$, the normal cuttings may be described as the following :—

(1.) All trees in that area which have reached the age of the rotation (or rather the size corresponding to that age), including trees removed for silvicultural or other reasons.
(2.) Thinning in the other age classes of the cutting area.
(3.) Thinnings, if necessary, in the part of the forest outside the area $\frac{A}{l}$.

The total of these cuttings might be called the normal yield. To carry out these operations correctly is one of the most arduous duties of the forester, whenever a sustained yield is the object of the proprietor. The only secure way of determining the increment, and consequently the current yield, is to make periodic measurements of the growing stock, as explained in Part IV.

d. Coppice and Coppice with Standards.

The normal yield of simple coppice is calculated in the same way as that for high forest clear cutting. It consists of the cutting of the oldest age gradation and any thinnings which may be necessary in the younger age gradations.

In coppice with standards the annual cutting area is the same as in simple coppice. The normal annual yield consists of :—

(1.) The underwood on the oldest age gradation, less those stems which are left to grow into standards.
(2.) The contents of the oldest, R years old, age gradation of the overwood.
(3.) The thinnings amongst the younger age gradations of overwood standing on the annual coupe, and occasionally in the younger age gradations on the rest of the area.
(4.) Necessary cleanings or thinnings in the underwood on the younger age gradations.

2. The Financial Value of the Normal Yield.

Having calculated the value of the normal growing stock, as indicated on page 148, the financial normal yield is obtained by multiplying that amount by $0{\cdot}0p$, where p represents the mean annual forest per cent.

CHAPTER VI.

RELATIONS BETWEEN GROWING STOCK, INCREMENT AND YIELD OF A NORMAL FOREST.

Relations exist between these three quantities which are of great importance in determining the yield. In order to bring these out clearly, the system of clear cutting in high forest will be used as an illustration.

a. Allotment of Increment during One Rotation.

It is assumed that a normal series of age gradations contains at the commencement of the rotation the normal growing stock. Dealing, in the first place, with the final yield only, it is clear that every year the oldest age gradation gives the normal final yield, and this is replaced, during the following growing season, by the laying on of the normal increment. The latter is added partly to the old growing stock and removed with it in the course of the first rotation ; while the balance of the annual increment accumulates on the cleared areas, and forms a new growing stock which is carried over into the second rotation. The question then arises, how much of the total increment of one rotation is added to the old and new growing stocks respectively ?

Making the calculation for spring, the youngest age gradation is at the commencement of the rotation 0 years old, and the oldest $r - 1$ years. The oldest of these gradations will be cut over after one year, when one year's increment has been added to it, while the increment laid on by this gradation during the remaining $r - 1$ years will be carried over into the second rotation. The gradation $r - 2$ years old at the commencement of the rotation will add two years increment by the time it is cut over, and $r - 2$ years increment is carried over into the second rotation, and so on down to

the gradation 0 years old at the commencement of the first rotation. Calling i the mean annual increment of one gradation in one year, and $r \times i = I$ the increment of r gradations in one year, the following division of the increment between the old and new growing stocks is obtained :—

Age of Gradation at the Commencement of the First Rotation.	Allotment of Increment to the Old Growing Stock.	Allotment of Increment to the New Growing Stock.
$r-1$	$1 \times i$	$I-i$
$r-2$	$2 \times i$	$I-2 \times i$
$r-3$	$3 \times i$	$I-3 \times i$
.		
.		
.		
1	$I-i$	i
0	I	0
Totals ..	$(i+I) \times \frac{r}{2}$	$(I-i) \times \frac{r}{2}$
Or	$I \times \frac{r}{2} + \frac{I}{2}$	$I \times \frac{r}{2} - \frac{I}{2}$

Making the division for the autumn, the values are as follows :—

Amount of increment $I \times \frac{r}{2} - \frac{I}{2} \qquad I \times \frac{r}{2} + \frac{I}{2}$

And for the middle of the growing season :—

Amount of increment $I \times \frac{r}{2} \qquad I \times \frac{r}{2}$.

Hence, the total final yield during the first rotation, calculated for the middle of the growing season, amounts to :—

Total final yield = the original growing stock plus the accumulated increment = $2 \times$ normal G_n. To this amount, the yield from the thinnings has to be added. This comes to the same amount year after year, as will be seen from the following example :—

Example.—Taking the yield table for larch I. quality, the yield of 80 acres under a rotation of 80 years would, for the middle of the growing season, be :—

Final yield = 6,070 × 80 = 485,600
Thinnings = 3,090 × 80 = 247,200

Total yield in 80 years .	. 732,800	cubic	feet.
Average annual yield, 80 acres .	9,160	,,	,,
,, ,, ,, per acre .	114	,,	,,

b. Relation between the Normal Yield and the Normal Growing Stock.

If the normal yield, Y_n, is divided by the normal growing stock G_n, and the quotient multiplied by 100, the " Utilization per Cent." is obtained :—

$$P_v = \frac{Y_n}{G_n} \times 100.$$

It gives the units of yield for every 100 units of growing stock, which, in a normal working section, is equal to the normal increment per cent. The utilization per cent. decreases with the increase of the rotation, as the increment per cent. decreases.

Example.—Taking the data for larch I. quality (page 124) we have :—

$G_n = 10\ (300 + 1{,}560 + 2{,}900 + 3{,}880 + 4{,}570 + 5{,}130 + 5{,}630 + 3{,}035)$

$G_n = 10 \times 27{,}005 = 270{,}050$. The yield is as follows :—

Final yield $= 6{,}070$ + intermittent yield $= 3{,}090$; total yield $= 9{,}160$.

Hence, utilization per cent. of final yield $= \frac{6{,}070}{270{,}050} \times 100 = 2{\cdot}25$ per cent.

Utilization per cent. of final + intermediate yield $= \frac{9{,}160}{270{,}050} \times 100 = 3{\cdot}39$ " "

The rate of utilization is used in Hundeshagen's method of determining the yield of forests, as explained in Part IV.

PART IV.

THE PREPARATION OF FOREST WORKING PLANS.

FOREST WORKING PLANS

The management of a forest depends, in the first place, on the objects which the proprietor has in view, in so far as they are not limited by the general laws of the country. These objects may differ widely according to the nature of the forest and the local conditions. Guided by the objects and the considerations set out in Part III. of this book, the forester constructs an ideal condition of the forest which meets the aims of the proprietor to the fullest extent. This ideal condition is generally called "The Normal Forest," at the realisation of which the forester should aim. He rarely succeeds in bringing his forest in every respect into the normal state, as, even if he should succeed, something unforeseen is sure to happen which will produce some imperfection in one way or another. Thus, the art of the forester consists in bringing his forest as near to the normal state as may be possible; and then keeping it in that condition.

The actual, or real, state of the forest may differ from the normal state in many respects, and the forester must determine which of these are of the greatest importance. These are (1) an abnormal increment, (2) an abnormal proportion amongst the age classes, and (3) an abnormal growing stock, to which, from a financial point of view may be added, (4) an abnormal forest per cent.

Either one or several of the conditions may be abnormal, and in the latter case the question arises, which of these the forester should take in hand in the first place. Just as a capitalist's first care is to make his capital yield him an appropriate interest, so must the forester see that a full increment takes place in his forest. The increment, above all other considerations, renders the capital invested in a forest active; it replaces, year by year, that part of the growing stock which has been removed by fellings. Without it, the growing stock will diminish until it finally disappears altogether. Hence, it must be the forester's first care to bring the increment up to its full or normal amount. This he does by regulating the cuttings in a suitable manner, followed by efficient regeneration and accompanied by rational tending of the growing

woods. All parts of the forest with a deficient or undesirable increment must either be filled up if young enough, or utilized and replaced by vigorous young woods. Take, for instance, many if not most of the oak woods in Britain. Quite a respectable number of cubic feet of timber may be standing on the area, but many of the trees are misshapen, or short in the bole, and the increment which they lay on is not only small, but it does not increase the value of the trees in the same degree as if it was laid on by trees with fine tall stems. In such cases, the undesirable stock should be removed and replaced by a better class of trees. Or, take the majority of Indian forests : they generally contain a considerable number of species, of which only a few, and sometimes even one only, are saleable. Here, the greater part of the increment is laid on by trees of little or no value. Rational forestry demands that, if not all, at any rate the greater part of the useless material should be removed and replaced by valuable species.

Next, a proper proportion and distribution of the age classes must be aimed at in all cases where a regular and sustained return is desired. Without it, the returns will be intermittent, or, even if there are mature woods available, it may not be possible to cut them for fear of damage being done to adjoining woods.

The realisation of a full and regular sustained yield is possible only, if both a full increment and a proper proportion of the age classes, as well as their suitable distribution over the forest, have been established. They may be found on separate areas, or they may be mixed on the same areas, as in the selection forest.

It has been shown that forests which have been brought into that condition contain also the normal growing stock ; the latter comes of itself, if the other two conditions are in order. At the same time, the real growing stock is of interest, since it shows the difference between the real and normal amount, and governs the determination of the yield, as well as the financial position during the immediate future, until the normal state has been reached.

Considering all these matters, it is clear that a proper plan or scheme must be devised which lays down the execution of the necessary measures in an orderly manner. A working plan has for its object to determine, according to time and locality, the entire management of the forest, so that the objects for which it is maintained may be realised as fully as possible. And this must

be done in an economic manner, for *extravagance has no place in forestry.*

Remembering now what has been said, it will easily be understood that a forest working plan must be based on the principles of silviculture ; it must not contravene them. To do justice to this task, the plan must provide :—

(1.) An exact and detailed account of the actual state of the forest in all its component parts.

(2.) The forest must be divided into divisions of workable size.

(3.) The leading principles of management must be indicated, and the yield estimated.

(4.) Arrangements must be made for the control of the execution of the plan and the record of all works which have been executed, so that every succeeding plan may be more accurate.

(5.) The whole material must then be brought together in a working plan report.

Until comparatively recent times, it was the fashion to commence by dealing with forests of some extent as a whole, fixing the yield, and then determining where and when it was to be obtained. Of late years, however, the procedure has been reversed. First of all, the requirements of each part of the forest, or of each wood, are determined, and the results are added up, thus giving the measures and works to be executed in the forest as a whole. If each part is brought into a healthy condition, the whole must be the same.

As the objects in view differ, it is impossible to lay down a general rule for the preparation of a working plan. For forests of great value yielding a high return, detailed plans are required ; under the reverse conditions, simple plans suffice. By way of illustration the following arrangement is given, but it must be understood that it may be too detailed in some cases, while further details may be required in others.

Working Plan Report.

INTRODUCTION.

CHAPTER I.—GENERAL DESCRIPTION.

1. Name and situation of forest ; name of proprietor.
2. Boundaries.

3. Area.
4. Configuration of the ground.
5. Rock and general character of the soil.
6. Climate.
7. Legal position of forest, rights and privileges.
8. Surrounding population and its requirements.
9. Markets, lines of export.
10. Prices of the several classes of produce.
11. Cost of extraction and transport to markets; supply of labour.
12. General description of forest growth.
13. Injuries to which the crop is exposed.
14. Rate of growth.
15. Yield tables, volume tables, form factors, reducing co-efficients, etc., used in the calculation of the volume and increment of the woods.
16. Organisation and strength of the forest staff.

Chapter II.—Division and Allotment of Areas.

Chapter III.—Detailed Description of Compartments.

Chapter IV.—Description of the Method of Treatment.

1. The objects of management.
2. Choice of species.
3. Choice of silvicultural system.
4. Determination of the rotation.
5. General lines of treatment.
6. Determination and regulation of the yield.

Chapter V.—Special Working Plans.

1. Plans of utilization.
    - *a.* Final cuttings.
    - *b.* Intermediate cuttings.
    - *c.* Minor produce.
2. Plan of formation.
3. Plan of other works.
4. Maps illustrating the condition of the forest and the proposed treatment.

Chapter VI.—Miscellaneous.

1. Organisation of the forest staff.
2. Financial forecast.
3. Miscellaneous observations.

Chapter VII.—Proposals for the Control of the Execution of the Working Plan.

In discussing the several headings of the working plan report it will be convenient to arrange the remarks into the following chapters :—

Chapter I.—Examination of the Forest, or Collection of Statistics.
" II.—Division and Allotment of the Area.
" III.—Determination of the Method of Treatment and General Lines of Management.
" IV.—Determination of the Yield.
" V.—Control of Execution and the Renewal of Working Plans.

The subjects under I., II., and III. are not easy to separate, because these chapters overlap to some extent. In practice, they are dealt with simultaneously, more especially Chapters I. and II., but in dealing with them here they must be taken one after the other. It is not possible to put the statistics together in proper order without having divided the forest into a number of working units ; nor is it possible to divide and allot the area to its several uses without having previously ascertained what each part of the forest contains. Again, the division and allotment of areas cannot be finally arranged until the method of treatment and the general lines of management have been provisionally laid down. It is for this reason that the division and allotment have been placed between the collection of statistics and the determination of the method of treatment.

The preparation of the special plans enumerated in Chapter V. of the Working Plan Report differs so much according to local conditions that no general patterns can be given. Some examples will be found in Appendices V. and VI.

At one time it was the practice to prepare working plans of high

forests for long periods of time, even as much as a whole rotation. Such a procedure is to be deprecated, because the conditions which govern the working of a forest change from time to time. Although the general lines of action must be determined for some time ahead so as to secure continuity of action, the detailed prescriptions for the management should be laid down only for a short period, say 10 or perhaps 20 years. This is especially desirable where a working plan is prepared for the first time, and where the data upon which it is based are as yet incomplete. It is desirable, in such cases, to revise the existing arrangements in the light of the experience gained during the actual working of the forest for a limited period.

CHAPTER I.

COLLECTION OF STATISTICS.

THE collection of statistics is of the first importance, because the whole fabric of the working plan rests upon the data which have been collected as regards the actual state of the forest, and the notes on the treatment which should be applied to each part. The statistics to be collected must refer, on the one hand, to each wood which forms part of the forest, and, on the other hand, to the general conditions in and around the forest as a whole which are likely to influence the management.

The data to be collected may be arranged under the following heads :—

I. Survey and determination of areas.
II. Description of each wood or compartment.
III. Past yields, receipts, and expenses.
IV. General conditions in and around the forest.
V. The statistical report.

The data under II. must be collected separately for each unit of working, or compartment ; those under III. may be given for each compartment, or each working section, or for the whole forest, according to the intensity of management.

SECTION I.—SURVEY AND DETERMINATION OF AREAS.

The survey yields the necessary data from which maps can be prepared and the area of the whole forest, as well as of its several divisions, ascertained. It is not intended to describe here the various methods of surveying, as this work must be done by professional surveyors ; the following remarks refer only to those points in which the forester must participate.

Before the survey is commenced, various preliminary matters must be attended to, such as :—

(1.) Regulation and demarcation of the boundaries of the forest and of those parts which are subject to servitudes.

(2.) Demarcation of all areas which are not destined for the production of wood, such as fields, meadows, pastures, swamps, rocky parts, and other areas unfit for growing woods.

(3.) The laying out of a suitable system of roads and rides, in so far as it can be done without a map, or with the help of a sketch map. What cannot be done in this respect before the commencement of the survey, should, if possible, be done during its progress—that is to say, as soon as the necessary data become available. If any part cannot be done until a map becomes available, an additional survey will be necessary.

(4.) Demarcation of the boundaries between woods of different species, ages, or qualities. The latter is necessary only in valuable forests.

The method of survey depends on the value of the forest as represented by its returns ; the higher the latter, the more minute should be the survey. Generally speaking, all main lines, such as the boundaries of the property and of the areas subject to servitudes, the roads and principal rides, should be surveyed with the theodolite and chain or measuring staff. The details, such as the limits of woods and of sub-compartments, may be done with the plane table or prismatic compass.

The area of the whole forest and its main parts should be ascertained by the method of co-ordinates ; the area of the compartments or woods may be ascertained with the planimeter, or a network of squares, each of which represents a fixed area.

Whenever practical, the survey should be based upon a previous triangulation.

The preparation of the maps will be dealt with in the last section of this chapter. Frequently, general maps of the area are already available ; if they are on a sufficiently large scale and reliable, only the additional details required for the management of the forest need be added.

SECTION II.—DESCRIPTION OF EACH WOOD OR COMPARTMENT.

The description of each wood, compartment, or other unit of working is of the first importance, because it gives information on which depends the whole management, viz. :—

(1.) The selection of species to be grown in the future.
(2.) The degree of ripeness of each wood.
(3.) The method of treatment of each wood, and the determination of the rotation.
(4.) The yield capacity of each wood and of the whole forest.

The minuteness of the investigation depends on the value of the forest and the intensity of management. Where these are high, detailed examination and record are called for ; where the returns are likely to be small, or where the demand for produce is considerably below the possible yield, a summary procedure may be indicated. The forester must in each case determine the actual procedure which he considers to be in keeping with the interests of the owner of the forest.

1. The Locality.

By locality is understood the soil (including the subsoil) and the climate, the latter depending on the situation. The agencies which are at work in the soil and the overlying air determine the *yield capacity* or *quality* of the locality.

The details regarding locality in relation to forest vegetation have been given in Silviculture (Volume II. of this Manual). From what has there been said, it will easily be understood that a description of the soil and climate must form part of the basis upon which a working plan rests.

In describing the climate and soil, the following points deserve attention :—

a. Climate.

(1.) The geographical position of the locality, as indicated by latitude and in many cases also longitude, especially where the vicinity of the sea, large lakes, or high mountains are likely to influence the climate (geographical climate).
(2.) The local peculiarities of the locality, such as altitude, aspect, slope, temperature, humidity of the air, rainfall, exposure to strong, cold, or dry winds, susceptibility to late or early frosts, or drought.
(3.) The surroundings of the locality, in so far as they are likely to affect the local climate.

b. Soil.

(1.) The underlying rock.

(2.) The mineral composition of the soil.

(3.) The organic admixtures of the soil.

(4.) The depth of the soil.

(5.) The degree of porosity.

(6.) The degree of moisture.

(7.) The surface covering of the soil or humus and its rate of decomposition.

In forests situated on level ground, the above data may be the same over a condiderable portion or the whole of the area, but in the hills they have frequently to be determined for each compartment, or even portions of one compartment, especially if it shows considerable differences of altitude, aspect, or slope.

All these factors combined produce a certain quality or yield capacity of the locality. How this is determined has been explained in Silviculture and in Forest Mensuration. Some further remarks on the subject will be found in the last part of this section.

2. The Growing Stock (or Stand).

The growing wood, or the crop produced on an area, represents the results of the activity of the locality under a certain treatment. All points which have influenced the quantity and quality of the results must be ascertained, to enable the forester to judge of the merits of the treatment hitherto followed and the advisability or otherwise of any changes in it.

a. Method of Treatment, or Silvicultural System.

The different methods of treatment are usually described in Silviculture (see also further on). At this stage, the forester must ascertain the system under which the wood has actually been managed in the past.

b. Species.

Pure woods are indicated by giving the species. In the case of *mixed* woods, the degree of mixture must be ascertained ; it can be given, either by adjectives, or, preferably, by decimals, placing

the whole as 1. These decimals should have reference to the area occupied by each species.

Example.—The following description—

Beech = ·5	Oak = ·3
Ash = ·2	Maple = a few,

would mean that ·5 of the area is occupied by beech, ·3 by oak, and ·2 by ash, with a few maples.

In the case of very valuable trees, such as old oaks, or teak trees in Burma, it may be desirable to give their actual number. The manner of admixture is expressed as "in single trees," "in groups," "in strips," or "irregularly distributed."

It is also necessary to state whether the mixture is permanent or temporary, whether it is of special silvicultural or financial importance, such as a shelter wood (or nurses) over another tender species, a soil-protection wood, standards of valuable species.

The undergrowth, shrubs, herbs, etc., should also be described.

c. *Density of the Growing Stock.*

To every method of treatment, as determined by the objects of management, corresponds a normal density of the growing stock. The degree of density may be defined as overcrowded, crowded, open, very open, interrupted, irregular, etc. Such terms are indefinite and subject to different interpretations. It is better to place the normal density equal to 1 and express the actual stocking in decimals of it. The degree of density can be determined by ocular estimate, or, more accurately, by comparing the basal area of the stems with that of a normally stocked wood, or, still more accurately, by comparing the volume of the wood with that of a fully stocked wood of the same age. When the density of stocking is insufficient, it should be stated whether the wood is generally open, or whether the deficiency is due to greater or smaller blanks.

By a *blank* is understood an area which, though it belongs to the wood-producing area, has no trees on it or so few that its complete re-stocking is necessary. Areas which are not destined for the production of trees are not included here, as they form part

of the areas set aside for other purposes, such as fields, meadows, etc., or are altogether unfit for the production of trees, such as bare rocks, boulder drifts and swampy ground which cannot be drained. As regards the latter, it is not always easy to draw the line between actual blanks and woodland, as they frequently have a thin stocking which may give a small return from time to time.

d. Age.

The methods of determining the age of trees and woods are given in Forest Mensuration.

An absolutely accurate determination of the age is necessary only when the data are required for the preparation of yield tables or other statistical purposes. Fairly approximate data suffice for the purposes of working plans.

In the case of even-aged or nearly even-aged woods, one or more sample trees are examined. If considerable differences of age exist in a wood, the limits should be given and the wood placed in that age class to which it belongs according to its economic character. If some older or younger groups exist which are not of sufficient extent to be enumerated as separate woods, this should be mentioned. The same holds good for a limited number of standards which are to be held over for a second rotation, or for young growth which has sprung up in an old wood.

In the case of woods which have been kept back in their development, the *economic* and not the actual age must be given. For instance, a young wood which has stood under heavy shelter and is now 30 years old, but of a development which is ordinarily reached in 10 years, must be entered as 10 years and not as 30 years old.

In the regeneration areas, the ages of the overwood and underwood must be given separately.

In selection forests, it suffices to give the limits of the age gradations, which are frequently determined by the number of years during which cuttings go once round the forest.

In coppice with standards, the ages of the overwood and underwood are given separately; for the former, the limits of the existing gradations are given. The age of coppice can easily be ascertained from the time when the last cutting occurred.

e. Origin and Past Treatment.

Whenever the necessary data can be ascertained, a short history of each wood should be prepared, giving the method of formation, whether by natural or artificial means, planting or sowing, the manner in which the wood has been tended, cleanings, thinnings, pruning, natural phenomena which have affected the development, etc. Such a history is very useful in judging the results of the past method of treatment and in determining that to be adopted in the future.

f. Volume.

All methods of determining the yield in material require a measurement of the volume, but to a different extent. For some, it is necessary to measure all woods, excepting only those which are very young and which are estimated, either direct, or with the assistance of yield tables. For other methods, only those woods require to be measured which will come under the axe during the immediate future of, say, 10 to 20 years.

Where a fine financial management is followed, all woods which are close to ripeness, or of which the ripeness is doubtful, must be accurately measured, so as to calculate the per cent. with which the capital is working.

For the determination of the capital value, an accurate measurement of the volume is indispensable.

The volume should be given separately for the different species if their value per unit of measurement differs considerably. It is useful to give all volumes in the same measure, as solid cubic feet. The proportion between the different classes of produce need, as a rule, only be given for each working section; preferably according to local proportionate figures, if such are available.

The different methods according to which the volume can be measured are described in Forest Mensuration. The choice of the method of measurement depends on the circumstances of each case.

g. Increment, Capital Value, and Forest Per Cent.

These matters have already been dealt with in Forest Valuation.

The determination of the quantity increment is required for the calculation of the yield. It must be done for all woods, if the

increment forms the principal basis for the determination of the yield. In that case, both normal and real increment must be ascertained. When the yield is fixed for only a limited period, the current increment must be ascertained for that number of years, or the mean annual increment of the past is substituted for it.

For financial questions, the volume-, quality-, and price-increments must be determined, as well as the capital invested in the forest, so as to calculate the indicating or the mean annual forest per cent. The former is necessary only for woods the financial ripeness of which is doubtful—that is to say, for woods which are approaching the normal final age, and woods which have suffered by injurious agencies, such as wind, snow, fire, insects, game, etc.

3. Determination of the Quality of each Wood.

a. General.

It has already been explained that by the quality of a wood or compartment is understood its yield capacity, as expressed by the quantity of produce which can be derived from it.

The yield capacity depends in the first place on the locality ; but injurious influences may have interfered with the full development of its producing factors, so that abnormal conditions may be the consequence. The forester distinguishes, therefore, between *normal and abnormal* or real *quality.* The quality is normal, if no exceptional injurious influences or faulty treatment have affected the development of the wood.

A further distinction must be made between the quality of the "locality" and that of the "growing wood" or standing crop. Either of the two can be normal or abnormal. The quality of the locality may be abnormal, in consequence of a variety of causes, such as the long-continued removal of litter, or excessive exposure to the effects of sun and air currents which has impoverished the soil ; or in consequence of unfavourable natural phenomena—for instance, if the ground has become swampy, temporarily denuded, or covered with moving sand. An abnormal condition of the growing wood may be produced by faulty treatment, by injurious external agencies, such as drought, frost, wind, fire,

insects, diseases of the trees, cattle grazing, unhealthy condition of the humus, etc.

For the preparation of working plans, only the actually existing, or real, quality of the locality should be taken into account, because the restoration of the normal quality is generally a slow process, if it is at all practicable. As regards the growing stock, both values are required, because its normal quality represents the real quality of the locality, and the real quality of the growing stock forms the basis for the calculation of the yield which the forest can give in the immediate future.

In Silviculture it has been explained that the quality of the locality can be ascertained—

(1.) By an assessment according to a crop of trees produced on the area in question, or on a similar soil in the vicinity; or

(2.) By an assessment according to the several factors of the locality.

It has also been stated that the second of these two methods, however carefully carried out, is always subject to grave errors, because an examination of the chemical composition, the physical properties of the soil, and a determination of the climate do not indicate the yield capacity of the locality for forestry with any degree of certainty; hence, it should be used only as an auxiliary of the first method, or when the latter is not available.

Thus, it will be seen that the determination of the quality of the locality depends practically on an examination of the wood which it has produced. In fact, a normal growing stock is the true expression for the real quality of the locality; the same investigation gives both the quality of the locality and of the existing crop.

For the purpose of obtaining an actual figure which represents the quality, the best way is to ascertain the volume (or height) of the growing stock, including all thinnings, and the number of years in which it has been produced. In dividing the produced volume by the age of the wood, the mean annual increment is obtained, which indicates the real quality of the wood. If the real mean annual increment of a wood is raised to the full, or normal, amount, the latter represents the real quality of the locality.

It is evident that in reality a multitude of different qualities exist, but for practical work they are grouped into a few, generally

not more than five, *quality classes*, which are numbered I. to V. Of these I. usually represents the best and V. the lowest quality. A more convenient way is to represent the best quality by 1 and the others by decimals of 1. Each of these quality classes represents a distinct yield capacity which differs with the species and method of treatment.

The normal quality of the wood can be determined only with the help of yield tables which represent the progress of volume, or increment, throughout life for each quality class ; hence, assessing the quality means, in this case, the selection of the proper yield table. This is done either by measuring the volume on a fully stocked, or normal, sample plot, or by ascertaining the average height of the dominant trees composing the wood. Fully stocked sample plots are not always available, and in such cases the height reached at a certain age provides the next best means of selecting the class of yield table to which the wood in question belongs. This latter method has been adopted by the British Forestry Commission in the preparation of British yield tables.

The difficulty is that for every species and silvicultural system a different set of yield tables is required. It may even be suggested to have different sets for different localities, so-called local yield tables, but such a procedure is likely to lead to confusion, as different standards of the quality classes are introduced into the account. Hence, general yield tables are to be preferred, even if the same degree of accuracy is not obtained as in the use of local tables. The difference is, however, not considerable, as experience has shown that, within reasonable limits, general tables give sufficiently accurate data for the preparation of working plans. The fact is that the sources of inaccuracy, unavoidable in the best methods of measuring the volume or height of a standing crop, are greater than those caused by using general yield tables for any particular locality.

British yield tables for larch, Norway spruce and Scots pine have so far been prepared and published by the Forestry Commission. They are found in Appendix IV. There are also given in Appendix IV. Continental yield tables for silver fir, oak, and beech, for use until British tables for these species become available. Some data on the development of Douglas fir, Corsican pine and Japanese larch are also given.

The quality of young woods cannot be judged by their volume, since the factors of the locality may not yet have found full expression in them; here, the quality must be estimated by the general condition of the crops and especially their height growth. Indeed, the latter may be used in older woods, at any rate as long as it has not ceased.

The determination of the quality from yield tables in the case of clear cutting in high forest and in coppice is a simple matter, as previously shown. The regeneration area under the uniform shelterwood system gives some trouble, because it is no longer fully stocked, so that the volume does not represent the quality; here, the determination must be based upon an investigation of the quality of the locality, combined with the condition of the shelterwood and young growth, especially the height growth. A similar procedure is followed in the case of coppice with standards and in selection forests. The quality of blanks is estimated from the soil and climate, or from that of adjoining woods which have been produced on soil of a similar description.

b. Reduction to One Quality.

Several methods of regulating the yield demand a reduction of the various qualities of woods, or working sections, to one common quality class. Such a reduction may be made as regards the locality or the growing wood, in each case as regards the normal or real quality. The method of procedure is the same in all cases.

The reduction is made with the help of the mean annual increment, or yield. It can be made under one of the following two conditions:—*Either* the total of the several reduced areas shall be equal to the actual area of the working section—in other words, the reduction is made to the mean quality of the whole area—*or* the above equality is not required, in which case any quality can be used as the standard, frequently that being chosen which exists over the greater part of the area.

Calculation with the Mean Quality.—By mean quality is understood that which, if it existed throughout the working section, would produce the same total yield as that produced by the several existing qualities in different parts of the working section.

Let $a_1, a_2, a_3 \ldots$ be the several areas,
" $y_1, y_2, y_3 \ldots$ the corresponding annual yields, or increment, per unit of area,
" $Y \ldots\ldots$ the mean yield per unit of area, then

$$a_1 \times y_1 + a_2 \times y_2 + a_3 \times y_3 + \ldots = Y (a_1 + a_2 + a_3 \ldots),$$

and

$$Y = \frac{a_1 y_1 + a_2 y_2 + a_3 y_3 + \ldots}{a_1 + a_2 + a_3 + \ldots} = \frac{\text{total annual yield}}{\text{total area}}.$$

Example :—

A working section of 100 acres contains—

Block (1) 20 acres with 60 cubic feet average increment,
" (2) 10 " " 50 " " "
" (3) 20 " " 40 " " "
" (4) 50 " " 30 " " " then—

Mean quality

$$Y = \frac{20 \times 60 + 10 \times 50 + 20 \times 40 + 50 \times 30}{100} = 40 \text{ cubic feet.}$$

By reduced or modified area is understood that which would produce, with a uniform quality $= Y$, the same yield as the actually existing areas with their own qualities. The reduced area of each block is obtained by applying, in each case, the inverse proportion of that which exists between the actual and the mean quality :—

$$Y : y = a : a' \text{ and reduced area } a' = \frac{a \times y}{Y}.$$

In the above example—

Block (1) The proportion is 60 : 40 ; hence the reduced area is obtained by means of the equation—

$$a'_1 = \frac{20 \times 60}{40} = 30 \quad \text{acres.}$$

$$a'_2 = \frac{10 \times 50}{40} = 12{\cdot}5 \quad ,,$$

$$a'_3 = \frac{20 \times 40}{40} = 20 \quad ,,$$

$$a'_4 = \frac{50 \times 30}{40} = 37{\cdot}5 \quad ,,$$

Total $= 100$ acres.

These figures show the proportion in which each block participates in the production of the total yield.

If now the forest is to be divided into annual coupes of equal yield capacity, the area to be placed in each is also obtained by calculating with the inverse proportion of the qualities.

Example.—The above forest shall be divided into ten coupes of equal yield capacity; then the reduced area of each coupe is $= \frac{100}{10} = 10$ acres. The real area of a coupe in each block is calculated as follows:—

Block (1) $60 : 40 = 10 : x_1$ and $x_1 = \frac{40 \times 10}{60} = 6{\cdot}667$ acres.

" (2) $50 : 40 = 10 : x_2$ " $x_2 = \frac{40 \times 10}{50} = 8{\cdot}000$ "

" (3) $40 : 40 = 10 : x_3$ " $x_3 = \frac{40 \times 10}{40} = 10{\cdot}000$ "

" (4) $30 : 40 = 10 : x_4$ " $x_4 = \frac{40 \times 10}{30} \times 13{\cdot}333$ "

or,

Coupe No. 1	= 6·667 acres		Taken from block No. 1.
" " 2	= 6·667 "		
" " 3	= 6·666 "		
" " 4	= 8·000 "		From block No. 2.
" " 5 = 2·0 + 7·5	= 9·500 "		Partly from No. 2 and partly No. 3.
" " 6	= 10·000 "		From block No. 3.
" " 7 = 2·5 + 10	= 12·5 "		Partly from No. 3 and partly No. 4.
" " 8	= 13·333 "		From block No. 4.
" " 9	= 13·333 "		
" " 10	= 13·334 "		
Total	= 100 acres.		

Calculation with any Suitable Quality.—In this case any quality can be used, whether it exists on the area or not.

The total reduced area is obtained by multiplying the several qualities by the corresponding areas and dividing the product by the selected standard quality. It may be greater, equal, or smaller than the actual area, according to the size of the standard quality:—

$$\text{Reduced } A = \frac{a_1 \times y_1 + a_2 \times y_2 + a_3 \times y_3 + \ldots}{Y'}.$$

The reduced areas of the several parts are obtained by the inverse proportion of their qualities to the standard quality; thus :—

$$\text{Reduced } a'_1 = \frac{a_1 \times y_1}{Y'},$$

$$\text{Reduced } a'_2 = \frac{a_2 \times y_2}{Y'},$$

etc.

Example, as above.—Let the standard quality = 50 cubic feet, then total reduced area =

$$\frac{20 \times 60 + 10 \times 50 + 20 \times 40 + 50 \times 30}{50} = 80 \text{ acres},$$

and the reduced area of :—

$$\text{Block (1) } \frac{20 \times 60}{50} = 24 \text{ acres.}$$

$$\text{,, (2) } \frac{10 \times 50}{50} = 10 \text{ ,,}$$

$$\text{,, (3) } \frac{20 \times 40}{50} = 16 \text{ ,,}$$

$$\text{,, (4) } \frac{50 \times 30}{50} = 30 \text{ ,,}$$

$$\text{Total} = 80 \text{ acres.}$$

$$\text{Reduced area of annual coupe} = \frac{80}{10} = 8 \text{ acres},$$

and the size of coupes in the several blocks :—

$$(1)\ x_1 = \frac{50 \times 8}{60} = 6{\cdot}667$$

$$(2)\ x_2 = \frac{50 \times 8}{50} = 8{\cdot}000$$

$$(3)\ x_3 = \frac{50 \times 8}{40} = 10{\cdot}000$$

$$(4)\ x_4 = \frac{50 \times 8}{30} = 13{\cdot}333;$$

as before.

It is obvious that the last-mentioned method is the more convenient of the two.

4. Notes Regarding Future Treatment.

While drawing up a description of each wood, it is very desirable to note down any observations which may strike the forester

regarding the future treatment. Such notes are, of course, only of a preliminary nature, because a final decision on the future treatment to be followed can be arrived at only after the management of the whole forest, or working section, has been laid down. Nevertheless, they are a great help during the progress of the work.

It is not possible to give a complete list of the points which should be attended to, as they differ according to circumstances ; the following may, however, be enumerated :—

(*a.*) Filling up the existing wood ; if so, the area to be treated and the species to be grown should be given ; also the method of sowing, planting, or other cultural operations.

(*b.*) Cleanings, thinnings or prunings during the working plan period ; the volume to be removed should be estimated.

(*c.*) Degree of ripeness of the principal, or final, crop, taking into consideration the objects of management ; if the latter are financial, the current forest per cent. should be calculated. If it appears advisable that final cuttings should be made, the method of cutting should be given, as well as an estimate of the volume to be removed.

(*d.*) Method of regeneration to be followed and the species to be grown, if this should occur during the working-plan period.

(*e.*) Measures to be taken for the protection of the wood against threatening dangers, especially fire.

(*f.*) Other works to be undertaken, such as construction of roads, draining, irrigation, etc.

(*g.*) Utilization of enclosures and improvement of boundaries where necessary and practicable.

(*h.*) Proposals regarding the formation of sub-compartments, or the abolishment of those which exist, with reasons for such proposals.

SECTION III.—PAST YIELDS, RECEIPTS, AND EXPENSES.

There is no surer basis in estimating future returns than those of the past ; hence, it is of importance to ascertain and note down the yield in material, the cash receipts, and costs for as many years as the available data admit. These data will, however, only be forthcoming if records have been kept for some time past.

As far as may be practicable, past yields, receipts and costs should be given for each unit of working—that is to say, each wood or compartment. If the records have not been kept in sufficient detail, the data for each working section should be given; the latter may also be sufficient where the management is as yet in a backward condition, or where the receipts are small.

The following notes indicate the class of information which may be required :—

1. Yield of Wood, or Major Produce.

The yield should be given separately—

(*a.*) For the principal species.

(*b.*) For the different classes of timber and firewood, according to size or value.

(*c.*) For final and intermediate returns separately.

(*d.*) The total cash receipts and the average price of the several classes of material, separated according to species.

The areas over which cuttings extended should, if possible, also be given, separately for final and intermediate cuttings.

2. Minor Produce.

Under this heading, the quantity of each article of minor produce which has been removed, and the cash receipts obtained for it should be given.

Receipts derived from areas not used for the production of wood, such as fields, meadows, etc., should be separately recorded.

3. Expenses.

These should be recorded separately for—

(*a.*) Cost of administration and protection.

(*b.*) Taxes, rates, etc.

(*c.*) Formation of woods.

(*d.*) Tending and amelioration.

(*e.*) Maintenance of boundaries.

(*f.*) Construction of roads, other means of transport, drainage, irrigation, and other works.

(*g.*) Cost of harvesting, separated according to major and minor produce.

4. Generally.

For forests worked on financial lines, the receipts and expenses should be so arranged that it is possible to ascertain—

(*a*.) The capital value of the forest, being the sum of the value of the soil plus value of the growing stock.

(*b*.) The forest rental, being the difference between all receipts and expenses.

(*c*.) The current forest per cent. of each wood whenever desirable.

(*d*.) The mean annual forest per cent. (see Part II., Forest Valuation).

SECTION IV.—GENERAL CONDITIONS IN AND AROUND THE FOREST.

The management of a forest depends, not only on the state of its several parts, but also on the general conditions which exist in and around it. The latter must, therefore, be ascertained at this early stage, and they should be used for a general description of the forest to be incorporated into the working-plan report.

The field of inquiry here indicated is of considerable extent; the following matters may be mentioned :—

(1.) Name and situation of forest, giving the latitude and longitude where necessary.

(2.) Description of boundaries and names of the adjoining properties and their owners.

(3.) Topographical features of the locality.

(4.) General description of the geology, soil and climate.

(5.) Former and present proprietors; financial position of the latter, whether the funds for formation, tending, administration, amelioration, etc., are available; whether specially heavy cuttings must be made to meet the demands of the proprietor.

(6.) Nature of proprietorship; whether full and unfettered property, or whether servitudes and privileges rest on it; in the latter case their extent should be recorded.

(7.) Rights enjoyed by the proprietor of the forest elsewhere, such as rights of way or floating, or rights over other lands, etc.

(8.) Requirements of the surrounding population, and condition

of the market for forest produce generally; special industries in the vicinity which require forest produce, such as mines, smelting works, saw mills; imports which compete with the local supply; substitutes for wood available in the vicinity.

(9.) Extent of forest offences; their causes; effect upon the forest; suggestions for their prevention.

(10.) Labour available in the vicinity; rate of wages.

(11.) Past system of management; changes introduced from time to time; prescriptions of former working plans and their effect upon the forest.

(12.) Natural phenomena which have affected the condition of the forest, such as storms, snow, frost, drought, fire, insects, fungi, etc.

(13.) Conditions of game and cattle grazing; their effect upon the forest.

(14.) Past seed years of the more important species.

(15.) Opportunities for consolidating the property, either by exchange or purchase; conversion of fields, meadows, etc., into forest, or the reverse.

(16.) The staff of the forest, its organisation and efficiency.

SECTION V.—THE STATISTICAL REPORT.

The data which have been collected in the manner indicated in the previous four sections must be brought together in a statistical report, accompanied by maps to illustrate it. The form of this report depends entirely on the circumstances of each case. In some instances, it will be necessary to go into minute details; in others, a more summary treatment is indicated. The following documents will ordinarily form part of the report:—

1. Register of Boundaries.

This should give—

(*a.*) The boundary marks in consecutive numbers.

(*b.*) The angles backwards and forwards at each point.

(*c.*) The horizontal distance between every two boundary marks.

(*d.*) The nature of the boundary line, whether a road, water-course, water-parting, ditch, cleared line, etc.

(*e.*) The names of adjoining properties and of their owners.

The value of the register of boundaries is considerably enhanced if its correctness has been acknowledged by the adjoining owners before the proper court of law.

2. Table of Areas.

The following form of this table is given as an illustration; it serves as a summary of all areas, and shows how each part is utilized :—

Locality.			Grand Total. In Acres.	Area used for the Production of Wood. In Acres.	Area not used for the Production of Wood. In Acres.				
Working Section or Block.	Compartment.	Sub-compartment.			Roads and Rides.	Fields.	Meadows.	Water, etc.	Total.
Cæsar's Camp.	1	*a*	29·2	26	·4	2·2	..	·6	3·2
		Etc.							

3. Description of Compartments.

This description may be drawn up in a tabular form or otherwise; the former is preferable, as it presents a more intelligible picture of the forest, and gives greater security that nothing has been overlooked. It is quite impossible to recommend any particular form for this table, but by way of illustration the appended form is given. (See pages 254–5.)

In this table, the quality of locality indicates that which corresponds to the normal quality of the growing stock. The real quality of the growing stock is given in decimals, the normal quality being placed equal to 1.

If the forest is worked on financial principles, further columns must be added for the quantity and quality increment, wherewith to calculate the forest per cent.

Description of

Locality.			Area, in Acres.			Boundaries.	Locality.
Working Section.	Compartment.	Sub-compartment.	Stocked	Blank.	Total.		
Cæsar's Camp	1	*a*	24	2	26	*North & East:* Sir A. Hayter's land. *South:* Compartments 13 and 12. *West:* Roman road.	*Elevation:* 420 feet above sea-level, sloping towards the east with moderate gradient, down to 380 feet. *Geological Formation:* Middle Bagshot sands. *Soil:* Loamy sand, fairly good in upper part of compartment, and good in lower part; no pan to 4 feet depth.

4. Table of Qualities of Locality.

Locality.			Total Area. Acres.	Quality Classes of Locality. Area in Acres.			Silvicultural System and Species.
Working Section.	Compartment.	Sub-compartment.		I. Best.	II. Middling.	III. Lowest.	
Cæsar's Camp	1	*a*	26	..	26	..	High forest of Scots pine with some broad-leaved trees here and there.
"	1	*b*	14	..	..	14	
"	2	..	38	..	32	6	
"	3	..	17	17	..	..	
"	4	..	31	..	16	15	
"	5	..	33	12	17	4	
"	6	..	31	..	25	6	
"	7	..	27	7	..	20	
	Etc.						
		Total	217	36	116	65	

COMPARTMENTS.

Growing Stock.					Quality of		Remarks, and Notes regarding Future Treatment.
Silvicultural System.	Species.	Age, in Years.	Mean Height in Feet.	Volume in solid Cubic Feet.	Locality.	Growing Stock.	
High Forest	Oak = ·4 Chestnut = ·2 Beech = ·1 Scots pine = ·3	70	Oak, Chestnut & Beech = 54 Scots pine = 60	Broad-leaved = 34,000 Scots pine = 28,800 62,800	II. (or middling)	·8	The mixture of species is uneven; the Scots pine is chiefly found in the northern part and the broad-leaved trees in the south; the northern part is well-stocked, the southern part is open; most of the oaks and chestnuts are frost-cracked. *Future Treatment.*—The southern part is so increment poor that it should be cut over during the next ten years, leaving the best oaks and chestnuts underplanted with beech. In the northern part only dead or dying trees should be removed during the next ten years.

Whenever the management is of a certain intensity, it is useful to prepare this table, as it enables the forester to calculate the total yield capacity of the area. In the table, each working section must be recorded separately, as the yield capacity depends on the species, silvicultural system, and rotation.

Assuming that the yield tables for Scots pine given in Appendix IV. apply to the woods in question, and that the latter are worked under a rotation of 80 years, the normal mean production per acre and year will be as follows:—

For the I. Quality class = 100 cubic feet.
II. „ „ = 86 „
III. „ „ = 67 „

The mean annual increment, or the yield capacity, of the area shown in the above table would therefore be—

Yield capacity = $36 \times 100 + 116 \times 86 + 65 \times 67 = 17{,}931$ cubic feet,

or average yield capacity per acre = $\frac{17{,}931}{217} = 83$ cubic feet.

This figure represents the normal yield; the real or actual yield depends on the quality of the growing stock and the ages of the several woods. Assuming that the mean quality (density of stocking) of all woods were equal to ·7, the actual yield would, for the present, be equal to—

$$17{,}931 \times \cdot 7 = 12{,}552 \text{ cubic feet,}$$

or 58 cubic feet per acre and year, while measures would have to be taken to increase the yield capacity in the future by growing more completely stocked woods.

5. Table of Age Classes.

This table is of great importance, as it gives a correct idea of the proportion of the different age classes, a matter which affects the determination of the yield in the future. It may be prepared in the following form :—

Table of Age Classes.

Locality.			Present Mean Age.	Age Classes, Areas in Acres.						
Working Section.	Com-part-ment.	Sub-com-part-ment.		I. 1-20.	II. 21-40.	III. 41-60.	IV. 61-80.	V. Over 80.	Blanks.	Total.
Cæsar's Camp	1	*a*	70	..	..	..	24	..	2	26
	1	*b*	35	..	14	..	..	..	..	14
	2	..	95	..	..	..	..	32	6	38
	3	..	54	..	..	17	..	..	..	17
	4	..	16	31	..	..	..	..	..	31
	5	..	46	..	..	33	..	..	..	33
	6	..	24	..	31	..	..	..	..	31
	7	..	86	..	..	..	..	27	..	27
			Total..	31	45	50	24	59	8	217

6. Table of Past Yields.

This table should give the past yields in produce for as many years as possible, and the mean annual yield calculated from these data, as in the example on the next page.

Similar statements are prepared for the different species, or groups of species, and a summary of the whole drawn up.

Where specially valuable timber has been cut, like oak standards, teak, etc., the results can be entered separately.

TABLE OF PAST YIELDS.
Material cut in Past Years, in solid Cubic Feet.

Year.	Conifers.								
	Final.			Intermediate.			Total.		
	Timber.	Fire-wood.	Total.	Timber.	Fire-wood.	Total.	Timber.	Fire-wood.	Total.
1881	7,200	1,750	8,950	4,700	1,300	6,000	11,900	3,050	14,950
1882	.								
.	.								
.	.								
.	.								
1890	.								
Total in 10 years	77,600	16,400	94,000	36,400	12,200	48,600	114,000	28,600	142,600
Annual average	7,760	1,640	9,400	3,640	1,220	4,860	11,400	2,860	14,260

REMARKS.—The area set aside for the production of wood amounted, in the beginning of 1881, to 217 acres.

The annual yield was fixed at 15,000 solid cubic feet: or 150,000 for the period of 10 years; hence, the average cuttings were below the fixed yield by 740 cubic feet annually.

7. MAPS.

It is most useful to represent on maps the data required for the preparation of a working plan, so far as this can be done. Such maps give at a glance a clear picture of the forest which impresses itself more readily on the mind than a lengthy description. As it is not possible to represent everything on one map, it is usual to represent different classes of information on different sets, such as the—

(*a.*) Topographical map.
(*b.*) Geological map.
(*c.*) Soil map.
(*d.*) Detailed map on a large scale.
(*e.*) Map showing the nature and age of the growing woods, called the stock map.
(*f.*) Map showing the working sections and cutting series.
(*g.*) Detailed road map.
(*h.*) Map showing the qualities of locality.

There is, however, no need for so many separate maps, as several of them can be combined into one. Ordinarily three maps suffice, namely :—

a. The Geological Map.

This map should show the geological formation of the upper layers, on which the nature of the soil depends. In it can also be shown the general topography of the area ; the limits of the various qualities of locality can be entered by lines of a distinguishing colour, the quality being indicated by a number.

b. The Detailed Map.

The scale of this map depends on circumstances. In India, the ordinary scale is 4 inches = 1 mile. In a few cases, maps on a scale of 8 inches = 1 mile, and in others of 2 inches = 1 mile, have been prepared.

The map should show, amongst other items :—

(1.) Name of forest and year of survey.

(2.) Boundaries, all boundary marks being indicated on the map and numbered ; boundaries between free property and parts subject to servitudes.

(3.) Names of adjoining properties and their owners.

(4.) Area, total as well as of the main divisions.

(5.) Areas not used for the production of wood.

(6.) Contour lines, or height curves.

(7.) The system of roads and rides, watercourses and other natural lines, with their names.

(8.) The boundaries of working sections, blocks, compartments and sub-compartments, with their names and numbers.

c. The Stock Map.

This has for its principal object to show the manner in which the area is stocked with wood ; a smaller scale than 4 inches = 1 mile generally suffices for it. The map should contain, apart from the necessary details, a representation of the existing species, silvicultural systems, and distribution of the age classes. This can be done in a variety of ways, as, for instance, in the following :—

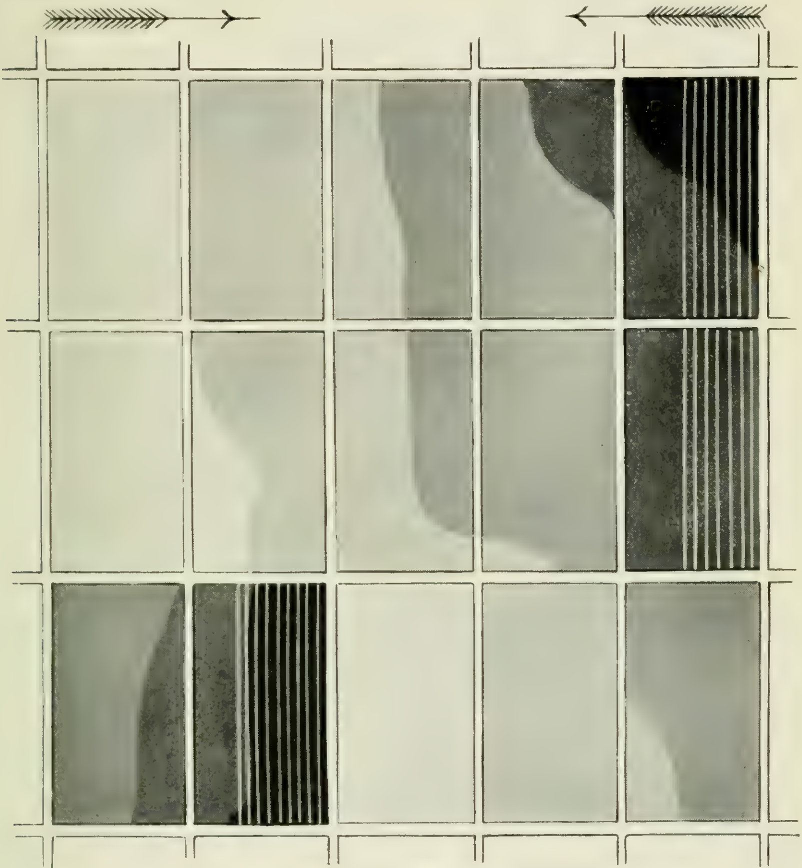
In *high forest* the principal species are shown by different

Fig. 54.

REPRESENTATION OF TWO CUTTING SERIES

(THE UPPER CONSISTING OF 10 COMPARTMENTS, THE LOWER OF 5).

PREVAILING WIND DIRECTION. CUTTING DIRECTION.



I. *Age Class* 1—20 *years old*
II. ,, ,, 21—40 ,, ,,
III ,, ,, 41—60 ,, ,,
IV. ,, ,, 61—80 ,, ,,
V. ,, ,, *over* 80 ,, ,,

Rotation = 80 years.

The White Lines indicate the coupes to be cleared during the next 10 *years.*

[*To face p.* 258.

washes ; the age classes by different shades of the same wash, the youngest being given the lightest, and the oldest the darkest shade ; the regeneration class receives some distinguishing mark.

Mixed woods may receive a separate wash, or they may be distinguished by the addition of small trees or marks of various colours.

Coppice woods may receive a separate wash, if shown on the same sheet.

Coppice with standards may be distinguished from coppice by the addition of miniature trees.

Selection forest may be indicated by colouring it with the wash of the principal species, and indicating other species by special marks.

Blanks remain uncoloured.

The stock map should be renewed whenever a new working plan is prepared ; if this is done, it gives, in the course of time, an excellent representation of the history of the forest.

By way of illustration, Fig. 54 is added. It illustrates two cutting series, a number of these constituting a working section, or a complete series of age gradations. Further details and illustrations will be found in Chapter II.

CHAPTER II.

DIVISION AND ALLOTMENT OF THE FOREST AREA.

1. The Working Circle.

By a working circle is understood the area which is managed under the provisions of one and the same working plan.

The area of a working circle depends on local conditions. It is intimately connected with the general organisation of a forest property. Assuming that the unit of an executive charge is represented by a *range*, a working circle may comprise all areas included in one range. Sometimes the conditions differ so much that different working plans are drawn up for parts of one range, but, as a rule, this should be avoided unless several small properties are comprised in one range. This occurs frequently in many European states, where Government forest officers manage both State and communal forests. Hence, it may be said that the minimum size would be the area of a property belonging to the same owner ; the maximum should ordinarily be the area forming one executive charge, or range. In some cases two or more ranges are worked under one working plan, but, with the advance in the intensity of management, such cases would disappear.

The division of an extensive property into ranges depends chiefly on :—

(1.) The situation, and

(2.) The intensity of management.

In the case of scattered blocks, in hilly country, or where means of rapid locomotion are wanting, a range will comprise a smaller area than if the property is consolidated, situated on level ground, or where railways and other means of locomotion, such as motor cars, enable the range officer to move rapidly from one part of his charge to another.

In forests which yield a small return the ranges may be large ; where the money yield is high, it pays best to make the ranges

small, so that an intense and detailed management may be possible.

Each working circle or range, as the case may be, must be further divided. The unit of that division is the *compartment.* A number of compartments are grouped together into *cutting series*, and a number of the latter form a *working section* consisting of a complete series of age gradations or age classes. In some cases a working section is identical with a working circle, or the latter may contain several of the former. The whole of this division is effected by utilizing, in addition to the outer boundaries, interior natural lines, such as waterpartings, watercourses, precipices, etc., and artificial lines, as roads, already constructed or projected, and rides.

Although the division of the working circle depends chiefly on the system of roads and rides, it is desirable, before indicating how they should be laid out, to explain more fully what is understood by compartment, sub-compartment, cutting series, and working section.

2. The Compartment.

By compartment is understood the unit of working; it forms the unit of the division of the forest.

This definition should never be lost sight of. If the boundaries of a compartment can be made to coincide with those of a wood showing a certain composition or age, so much the better, but it is a mistake to insist upon such an arrangement; the main point is that each compartment should be of a certain size, so as to realise its objects as the unit of working. If that area includes two or more different kinds of growing woods, they may be distinguished as sub-compartments; but the boundaries of the compartment should never be twisted out of shape for the sake of including only one kind of growing stock.

The formation of compartments is necessary—

(1.) For general orientation, so as to enable the forester to define accurately any particular part of the area.

(2.) To render all parts of the forest easily accessible, since one or more sides of the compartment should abut on roads or rides.

(3.) To assist in the prevention of fires, and to enable the forester to stop any which may have broken out.

(4.) For the location of the annual or periodic coupes.

(5.) To facilitate the transport of forest produce.

(6.) To obviate the necessity for repeated surveys of the coupes.

(7.) In some cases, to facilitate hunting and shooting.

The shape of compartments depends on the configuration of the ground. In the plains, a rectangular shape (with sides 2 : 1, or 3 : 2) is most suitable. On hilly ground, such a shape is not always practicable; but the actual shape should, as far as possible, approach that of a rectangle.

The size of compartments cannot be laid down; it depends chiefly on—

(1.) The size of the working circle.

(2.) The intensity of management.

(3.) The extent of danger from fire.

3. The Sub-compartment.

If, within the limits of a compartment, considerable differences exist in respect of species, silvicultural system, age of growing stock, quality of locality, etc., it may be divided into two or more sub-compartments; the latter may be temporary if the differences will disappear after some time, or permanent. Sub-compartments may be marked by shallow ditches or other cheap boundary marks. They form the units of treatment.

The forester should not go too far in the formation of sub-compartments, as it is accompanied by additional expenditure. As a rule, sub-compartments should be formed only if the additional income derived from different treatment at least covers the additional expense involved thereby. The formation of sub-compartments depends on the intensity of management.

4. The Working Section.

A part of a working circle which forms a separate series of age gradations or classes is called a working section. If a working circle consists of only one series of age classes, it is identical with a working section. In working circles of some extent, however, different conditions may demand the establishment of two or

more series of age classes—that is to say, a division of the working circle into two or more working sections. The principal causes which demand the formation of working sections are the following :—

a. Species.

When several species appear in a working circle as pure woods, they must be placed in different working sections if they require essentially different treatment, or if a certain quantity of material of each species has to be cut annually. When, on the other hand, the several species appear in mixed woods, such a separation is neither practicable nor necessary.

b. Silvicultural System.

Each silvicultural system may demand the formation of a separate working section. If, for instance, part of a high forest is treated under the uniform system, and another part as a selection forest, each part must be formed into a separate working section. Coppice woods and coppice with standards must always form separate working sections.

c. Rotation.

Even in the case of the same species and silvicultural system, areas worked under different rotations must be placed in different working sections whenever an even, or approximately even, annual yield is expected. Unless this is done, it will happen, either that the annual yield is uneven, or, if the same quantity is cut every year, that the different rotations merge into one.

d. Servitudes.

If part of a working circle is subject to servitudes, it should be placed in a separate working section ; this is necessary to protect the interests of the owner, as well as of the right holder.

e. Differences in the Quality of the Locality.

Differences in the quality of the locality cause the establishment of different working sections, if they necessitate the growing

of different species, or the adoption of different treatment or rotations.

f. Distribution of Cuttings.

If cuttings must be made annually in different parts of the working circle, so as to supply local demands, it is often advisable to form different working sections, though this may not be absolutely necessary.

g. Size of the Working Circle.

When the area of a working circle exceeds a certain limit, it may be more convenient to divide it into several working sections, although no difference in the character of the growing stock and the management exists. In this way, better arrangements can be made for the execution of the work.

h. Generally.

A working circle, consisting of several working sections, is said to be normal if each separate working section is in a normal state.

Although the formation of working sections is in certain cases unavoidable, the forester should not go to extremes in this respect. A separate record must be kept for each working section, and they cause extra trouble and expense in other ways ; hence, moderate differences of conditions, especially in the rotation, should not induce the forester to introduce separate working sections.

The question may be asked, why a separate working plan should not be drawn up for each working section, thus making the latter always identical with a working circle ? Such a procedure is not desirable, because it involves extra labour and repetitions in the working plan report. It is preferable, whenever practicable, to have one working plan for each executive charge, because the management of the different working sections can be so arranged that they supplement each other, thus enabling the forester to provide for a proper allotment of work amongst the staff, and a proper distribution of the yield. Where the areas managed on different lines are mixed up with each other, the division of a working circle into two or more working sections becomes a necessity. The areas belonging to one working section need not form a consolidated block ; they may be scattered amongst areas forming another working section.

Sketch of the Existing Division of a Working Circle into Working Sections, Compartments and Sub-Compartments, in 1925.

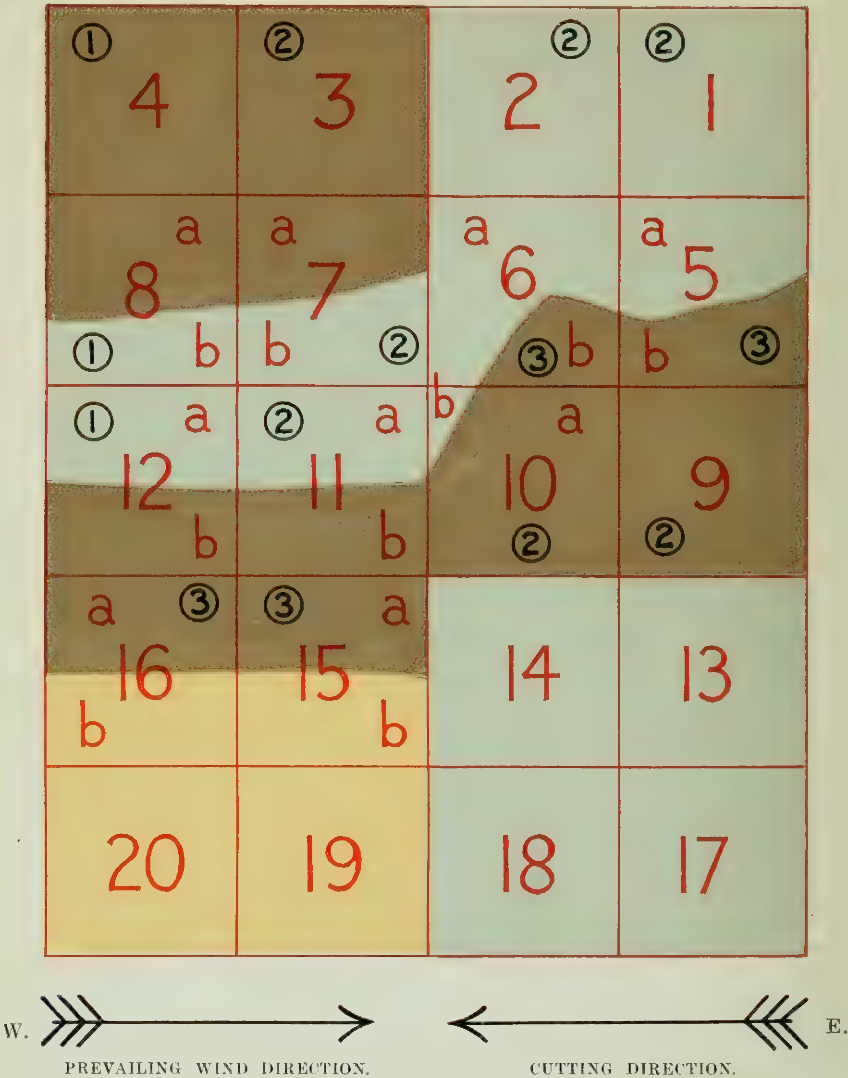


Fig. 55a.

Explanation of Fig. 55, *representing an Executive Charge, or Range.*

The area represents one Working Circle, which, by a system of rides, has been divided into 20 compartments, stocked as follows :—

Working Section I. = Oak high forest with an admixture of beech, comprising compartments 3, 4, 5*b*, 6*b*, 7*a*, 8*a*, 9, 10*a*, 11*b*, 12*b*, 15*a*, 16*a*.

Working Section II. = Conifer high forest, comprising compartments 1, 2 5*a*, 6*a*, 7*b*, 8*b*, 10*b*, 11*a*, 12*a*, 13, 14, 17, 18.

Working Section III. = Coppice woods, comprising compartments 15*b*, 16*b*, 19, 20.

It has been decided that sub-compartments 5*b* and 6*b*, being of III. quality class, shall be converted into conifer woods ; sub-compartments 7*b*, 8*b*, 10*b*, 11*a*, and 12*a*, into oak with beech, being I. and II. quality class ; while 15*a* and 16*a*, being III. quality class, will be converted into coppice woods.

Sketch of a Division of a Working Circle to be Established during the First Rotation.

PREVAILING WIND DIRECTION. CUTTING DIRECTION.

Fig. 55 b.

Division into ten Cutting Series, each consisting of two Compartments.

Working Section I.	*Conifers.*	Cutting Series	A =	Compartments	1 and 2
	,,	,, ,,	B =	,,	5 ,, 6
	,,	,, ,,	C =	,,	13 ,, 14
	,,	,, ,,	D =	,,	17 ,, 18
Working Section II.	*Oak.*	,, ,,	E =	,,	3 ,, 4
	,,	,, ,,	F =	,,	7 ,, 8
	,,	,, ,,	G =	,,	9 ,, 10
	,,	,, ,,	H =	,,	11 ,, 12
Working Section III.	*Coppice.*	,, ,,	I =	,,	15 ,, 16
	,,	,, ,,	K =	,,	19 ,, 20

5. The Cutting Series.

A working section in its simplest shape should consist of a series of age gradations equal to the number of years (or periods) in the rotation, so arranged that cuttings commence in the oldest age gradation and proceed steadily towards the youngest in the direction which is determined by the circumstances of each case. It has, however, been pointed out above, that such a simple arrangement is, in the case of high forest, not always admissible, and that every working section in such a forest must be further divided into several parts, which are called "*cutting series*." Only such a further division gives the necessary order and elasticity to the arrangement of the coupes.

Each cutting series should comprise a number of gradations, the ages of which differ by a certain number of years (see diagram on page 209); ordinarily, a certain number of cutting series together form one complete series of age gradations, or a working section.

The number of age gradations to be included in one cutting series depends on local circumstances. On the whole, small cutting series are desirable, as each gives a point of attack where cuttings can be made. (See Fig. 53, page 211.) Amongst the advantages of small cutting series, the following may be mentioned :—

(1.) The special requirements of each wood can be met at the right time; if a cutting is desirable at a given time, it can be made without interfering with the safety of adjoining woods.

(2.) A suitable change of coupes can be arranged, so as to protect the forest against the dangers which may make themselves felt if two or more annual coupes adjoin each other.

(3.) The establishment of small cutting series assists the forester in distributing the yields to meet local demands.

In order to realise these advantages, it is necessary that each cutting series should receive a shape and be so situated that the coupes can be suitably arranged, and that cutting in one series does not interfere with the requirements of adjoining series; in other words, each cutting series must be independent of its neighbour. Where these conditions do not exist, they must be specially

provided by the clearance of broad rides between the cutting series, called "severance cuttings."

6. Severance Cuttings.

By a severance cutting is understood a cleared strip of varying breadth by which two woods are separated in the general direction of the cuttings, at a place where some time afterwards regular cuttings are to commence.

Severance cuttings are necessary whenever an existing cutting series is too long, and when it is desirable to divide it into two or more series, or where an older wood is situated on the windward side of a younger wood. Their object is to accustom the edge

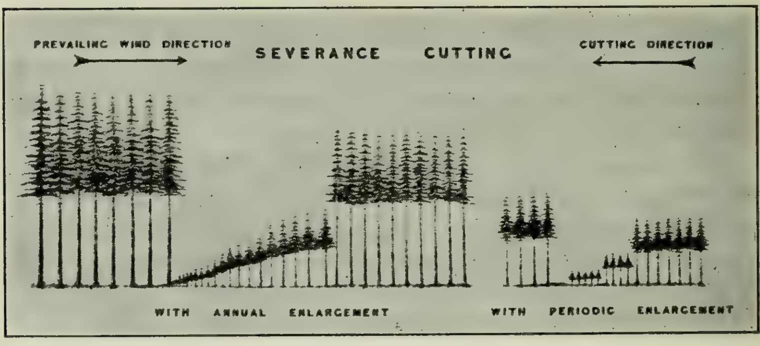


Fig. 56.—After Wagner.

trees of the wood on the leeward side to a free position, so that they may develop into storm-firm trees, and be able to withstand the effects of strong winds when the wood on the windward side has been cut. The above illustration will explain this.

Severance cuttings need not be straight; they may, if necessary, be curved, or run along two or three sides of a wood. The latter is necessary where the prevailing wind direction is not constant, but oscillates, say, from north-west to south-west. The breadth of severance cuttings differs according to species, their height growth, and the strength of threatening winds; it will ordinarily range between 30 and 60 feet.

Severance cuttings must be made while the wood to be protected is still young and capable of developing firm edge trees; such a

development is generally no longer possible after the trees have passed middle age. They must be made, in the windward wood, some 15 to 20 years before the regular cuttings are commenced. Where danger from windfalls is great, it is desirable first to clear a narrow strip, and to widen it a few years afterwards in one or more instalments, so as gradually to accustom the edge trees to the effects of strong winds. If the severance cutting is not to form a road or ride it is at once re-stocked, so as to avoid loss of increment, and because the existence of a young wood in front of that to be protected is an additional safeguard against windfalls. When a severance cutting is made along an existing road or ride, it consists of a widening of the road on the windward side of it.

If the proper time for making a severance cutting is past, and the wood to be protected is too old, it would be a dangerous procedure to make such a cutting. In that case, it is better to make a series of thinnings in the strip along the edge of the wood to be protected before cuttings in the windward wood are commenced. Whether this measure will have the desired effect is doubtful, but it is better than to risk a regular severance cutting.

7. The System of Roads and Rides.

As already indicated, working sections, cutting series and compartments must be separated from each other by natural or artificial lines. Apart from suitable natural boundary lines—such as waterpartings, watercourses, precipices, fields, meadows, etc.—roads are the best boundaries of compartments and cutting series, because they facilitate the transport of the produce. It is, therefore, desirable that, in the first instance, a suitable network of roads should be designed and marked on the ground. Roads alone, however, rarely suffice. In some cases, roads already exist which are not suitable for boundaries, in others even new roads must be so laid out that they cannot be used as boundaries, because they must lead in the direction of the places of consumption. Besides, on hilly or swampy ground they often follow a direction which renders them unfit to serve as boundaries.

The missing division lines are provided by a system of rides, that is to say by cleared strips of various breadths. A distinction is made between major and minor rides.

a. Major Rides.

In so far as roads or natural lines are not available, working sections, and in many cases cutting series, should be bounded by major rides. These should, as far as possible, run parallel to the prevailing wind direction, so that the adjoining woods on both sides produce wind-firm edges. Deviations from this rule may be necessary in hilly country, and where young crops require shelter against the sun.

In coppice and coppice with standards, the major rides need not be broad, unless they are used as roads for the transport of the material. In high forest, they must be broader, because they are used as severance cuttings. In the case of woods consisting of species which are easily thrown by wind, they should not be less than 30 feet broad, and if the major ride is also used as a fire line, it may be still broader.

The edges of the woods consisting of species easily thrown by wind, if bordering on major rides, should be heavily thinned from an early age onward, so as to produce strongly developed trees.

Major rides may be utilized for stacking wood. Their area is entered as non-productive of trees ; in many cases, however, they produce grass.

In young woods, the major rides should be cut at once, while the edge trees are capable of producing a strong root system ; in woods which are past middle age, only 6 to 8 feet broad lines should be cleared in the first instance, which are widened to the required breadth when the adjoining woods are cut over.

b. Minor Rides.

Minor rides should run, more or less, at right angles to major rides ; they complete the delimitation of the compartments. Minor rides need not be more than 6 to 8 feet broad, unless they are used as fire lines. The direction of the coupes must be determined according to local conditions ; no general rule can be laid down. In the case of clear cutting and artificial regeneration the coupes should be so arranged that the young crop receives the best possible protection against drought. On sloping ground they should proceed from the top downwards, etc.

c. The Network of Rides.

Major and minor rides together form the network or system of rides. The laying out of it depends, especially in the case of shallow-rooted species, chiefly on the prevailing wind direction. In the plains, the latter can generally be determined without much trouble. In mountainous districts, the matter is frequently beset by difficulties, because the configuration of the ground may produce a local direction which differs from the general direction. No rule can be laid down for such deviations ; the question must be studied on the spot. The direction can frequently be recognised by the shape of the crowns of trees, by a slanting position of the stems, and by the direction in which trees have been thrown. As regards the latter, it must not be overlooked that local storms sometimes throw trees in a direction which differs from the ordinary direction of gales. In many cases, reliable information can be obtained from local people who have lived for some time in the locality.

The laying out of the system of rides is of great importance, because it is used in the protection of the woods against natural phenomena, and it leads to order in the management. These advantages outweigh the loss of productive area which is, after all, very limited. Regular networks of rides with right angles at the corners are practicable only in the plains ; on hilly ground they must accommodate themselves to the configuration of the area. The example given below will illustrate this. The forest occupies a ridge, the slope of which is indicated by dotted contour lines, - - - - . The top of the ridge, being much exposed, must be treated as a separate working section worked under the selection system ; it is separated from the rest by a major ride (B). The slopes are treated under the uniform system, and they are divided into two parts by the major rides (A) (B) and (C). The numbers (1) (2) . . . indicate the minor rides, and 1, 2, 3 . . . the compartments. The prevailing wind blows from the west.

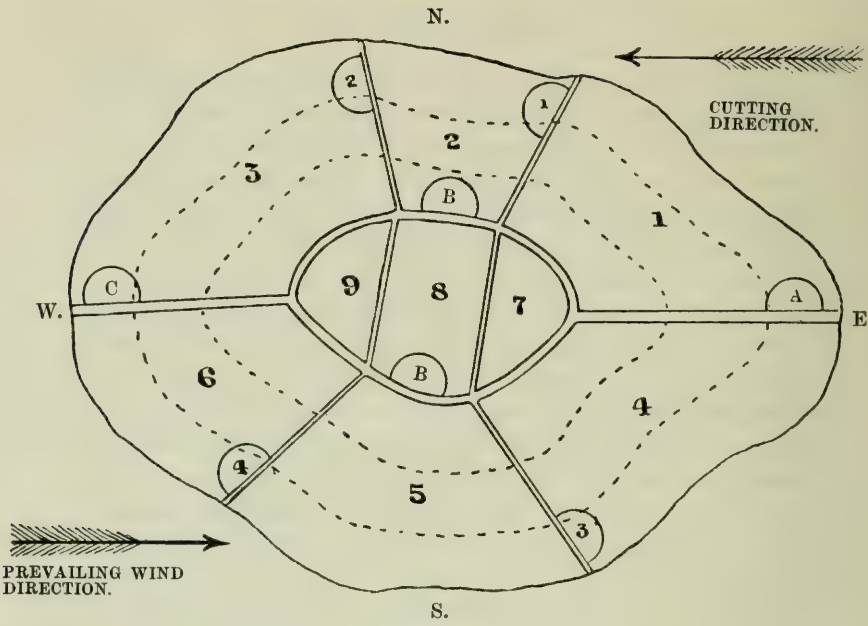


Fig. 57.

The division would probably be somewhat on the following lines :—

Working Section I., Uniform System.

Cutting	Series	*A*	comprises	compartments	1 & 2
,,	,,	*B*	,,	compartment	3
,,	,,	*C*	,,	,,	4
,,	,,	*D*	,,	compartments	5 & 6

Working Section II., Selection System, comprises compartments 7, 8, and 9.

The general cutting direction would be from east to west, a direction which is indicated by the numbering of the compartments. The coupes in compartments 1, 2, and 3, being on a slope with a direction from N.E. to N.W., would probably run parallel to the minor rides. Those of compartments 4, 5, and 6, being a slope running from S.E. to S.W., would best be arranged running from the highest part gradually down to the lower edge, so as to protect the young growth against the drying effect of the sun.

8. Demarcation and Numbering of the Divisions of a Forest.

It is generally desirable that all interior boundary lines should be demarcated by boundary marks, so that they can be recognised if parts of them should have become obliterated in consequence of cuttings, windfalls, etc. For this purpose, boundary marks may be placed at all points where rides cross, or where they form an angle. If straight rides are very long, it is useful to have intermediate marks at suitable distances. Such marks are placed on one side of the rides, so that they may not interfere with the transport of the produce ; it is useful always to choose the same side, say the north side of the major rides and the east side of the minor rides.

The methods of naming and numbering the divisions differ much. The author recommends the following :—

(*a.*) Working sections receive Roman numbers = I., II. . . .

(*b.*) Cutting series receive slanting capital letters = *A*, *B*. . . .

(*c.*) Compartments receive Arabic numbers = 1, 2. . . .

(*d.*) Sub-compartments receive the same with small Roman letters attached, 1_a, 1_b. . . .

(*e.*) Major rides are indicated by two parallel lines.

(*f.*) Minor rides are indicated by single lines.

(*g.*) Metalled roads should be indicated by heavy black lines.

Sometimes a number of compartments are joined into a " block " ; if so, the latter should receive a name.

The numbering of compartments should be consecutive throughout the working circle, unless the latter consists of two or more entirely separated blocks ; it leads to confusion to have a separate series for each working section. The numbering should be done so as to indicate the cutting direction.

In the French State forests, the following system of numbering the divisions was prescribed until a short time ago :—

Working sections are numbered = I., II., III. . . .
Periodic blocks ,, ,, = 1, 2, 3. . . .
Compartments ,, ,, = *A*, *B*, *C*, . . . with the addition of the number of the periodic block ; thus IV. C_2 means Working Section IV., compartment *C* in the 2nd periodic block.

CHAPTER III.

DETERMINATION OF THE METHOD OF TREATMENT.

On the basis of the statistical report and the division and allotment of the area, the forester decides upon the method according to which the forest is to be treated. The selection of the method depends on a variety of matters, of which the more important may be mentioned :—

(*a.*) The legal position of the forest, the existence of rights of third parties, or privileges enjoyed by them.

(*b.*) The objects aimed at by the proprietor, whether he be a private person or the State. He should decide whether he aims at indirect or direct effects ; in the latter case, he should indicate the classes of produce which he desires to obtain.

(*c.*) The character and quality of the locality.

(*d.*) The existing growing stock according to species and the degree of their development ; also the dangers to which the existing species and the soil are exposed.

(*e.*) The conditions of the market, the extent of the demand, and the supply of produce from other forests.

(*f.*) The supply and cost of labour.

These and other considerations influence the selection of the most suitable method. The following subjects deserve special attention.

1. Choice of Species.

The subject is dealt with in Silviculture (see pages 122—128 of Vol. II., 4th edition). In the present case, the forester should carefully ascertain the degree to which the existing species have met the objects of the proprietor, and proved to be suitable for the locality. If they do not answer, the forester should not hesitate to change them for other more suitable species. At the same time, the introduction of new species should not be lightly

undertaken, as it generally involves some temporary loss, and it may lead to disappointment in the future. Species which have been tried within a reasonable distance of the locality and given satisfactory results should receive first consideration. The cultivation of untried, and especially exotic, species should, in the first place, be tried on a small scale. In such cases, the formation of mixed woods deserves consideration, as they give a choice between two species as to which is to be kept for the final crop.

2. The Method of Formation.

The various methods of formation are dealt with in Silviculture (see pages 275—284, of Vol. II., 4th edition). The choice depends on the species, the nature of the locality, and the selected silvicultural system. Artificial regeneration generally forms part of the system of clear cutting in high forest, but it may also be done under shelterwoods ; it is necessary in the case of first afforestations, and frequently also when a change in the species is contemplated. The choice between direct sowing and planting depends on the species and local conditions.

Natural regeneration is cheaper than sowing and planting and, if successful, leads to fully stocked woods. In the case of many species, however, seed years do not always come when they are wanted, in which case the operation of regeneration may be seriously disturbed ; the loss of time and other accompanying disadvantages may more than outweigh the saving in the original outlay. Moreover, natural regeneration must frequently be augmented by planting or sowing.

The choice of the method of formation in high forest depends practically on the degree of moisture of the locality. Where the rainfall is scanty and irregularly distributed over the seasons of the year, and where long droughts are of annual occurrence, regeneration should be effected under a shelterwood, either provided naturally or by planting and sowing. Where the opposite conditions prevail, planting and sowing on clear land is admissible. The latter is necessary in the case of highly light-demanding species ; on the other hand, species which are tender while young should be raised under a shelterwood.

The quality of the locality is also of great importance. Generally speaking, regeneration on cleared areas may be fully justified in

localities with a high yield capacity, while regeneration under shelterwoods is indicated on areas of middling yield capacity and essential on those of poor quality, especially in hilly localities.

3. The Method of Tending.

(See pages 287—323, of Vol. II., 4th edition.)

To sow or plant an area is a comparatively simple business when once the most suitable species has been selected; the process of natural regeneration requires considerable skill; the most important work of the forester is the application of a suitable method of tending, and especially the method of thinning the wood from the completion of the process of regeneration to the time when the wood is ripe for final cutting. The tending must be so arranged that throughout life each tree receives just that growing space which produces the most profitable results according to the objects of the proprietor.

Views on this subject differ much. Until some 30 years ago, the method of early and heavy thinnings prevailed in Britain, giving unsatisfactory results, while on the Continent the system of light and frequently repeated thinnings prevailed, leading to fully stocked woods of high value. Since then, a change has taken place in both cases, but in opposite directions. The system of lighter thinnings has found favour in Britain, while a number of Continental foresters now advocate heavy thinnings. It has been proved that there is not much difference between the two systems as regards the total production, but there is a different division of it between thinnings and final returns. In some cases, as much as half the increment is taken out in the thinnings, reducing the final yield to the other half. The thinnings are no longer restricted to the removal of suppressed and dominated trees; a part of the dominating trees is also taken out even at a comparatively early age, while the suppressed and dominated trees are left (*Eclaircies par le haut*). The justification for this is the belief that the system gives better financial results. But is this so? No doubt, early and comparatively heavy thinnings act favourably in a financial respect, but they generally give too much growing space to the remaining dominating trees, which are liable to produce in the final cutting a less valuable class of timber, so that the previous

advantage may be more than wiped out. This consideration limits the heaviness of the thinnings ; they should never be made so heavy that they interfere with the most favourable development of the trees that will constitute the final crop. The most favourable proportion between thinnings and final crop can be determined only by the collection of comparative statistics, when the heavily thinned woods reach maturity, and their value can be compared with that of woods produced under the system of light and frequently repeated thinnings.

4. Choice of Rotation.

(See pages 188—195 of this volume.)

The determination of the rotation depends chiefly on the species, the method of treatment and the objects of the proprietor. The financial aspect should never be lost sight of, but there are weighty reasons why departures from the financial rotation are desirable and even necessary. Amongst these, the preservation, or even improvement, of the yield capacity of the locality demands first consideration, and next the class of the desired produce. In the latter case, frequently, a special size of the trees in the final crop is substituted for a rotation fixed by a certain number of years.

5. The Silvicultural Systems.

A description of these is given in Silviculture, where it is required to understand the various methods of the formation and regeneration of woods. Here it is wanted especially for the determination and regulation of the yield. The number of systems is very large, some 70 having been enumerated. There are a limited number of principal systems, while the rest are modifications of these. They may be classified in various ways, of which the following will serve as an illustration :—

I.—*Principal Systems.*

(A.) High or seedling forest.
- (1.) Clear cutting and subsequent regeneration.
- (2.) Regeneration under a shelterwood.
  - (*a.*) By treating one or several compartments in a uniform manner (the compartment or uniform system, with various modifications).

(*b.*) By groups.
(*c.*) By strips.
(*d.*) By strips and groups combined.
(*e.*) By single trees (the selection system).

(B.) The coppice system.

(C.) The combination of the seedling and coppice systems (coppice with standard system).

II.—*Auxiliary Systems.*

(1.) High forest with standards.
(2.) Two-storied high forest.
(3.) High forest with soil protection wood.
(4.) Forestry combined with the growth of field crops.
(5.) Forestry combined with pasture.
(6.) Forestry combined with the rearing of game.

Any of these systems may be utilised in the determination and regulation of the yield, as shown in the next chapter.

CHAPTER IV.

DETERMINATION AND REGULATION OF THE YIELD.

As long as the owner of a forest is satisfied with intermittent returns, the regulation of the yield is strictly governed by silvicultural considerations ; that is to say, thinnings are made when they are necessary, and every wood is cut over when it is just ripe, according to the objects of management. If the owner desires a sustained annual or periodic yield of equal or approximately equal quantity, although the forest is at the time not in a normal state, the various cuttings may have to be made at other times. All such deviations demand certain sacrifices on the part of the owner, which differ according to the actual condition of the forest and the objects of management. These sacrifices are due to the fact that the final cuttings may have to be made at ages differing from the normal, as determined by the objects of management ; even thinnings may have to be postponed, instead of being made

when the condition of the woods demands them. These deviations may be brought about by a surplus or deficiency of mature woods, or by their being so situated that they cannot be cut at the proper time, out of consideration for the safety of adjoining woods.

The task of the forester in such cases is to secure a sustained annual yield, and yet to lead the forest, with the smallest possible loss to the owner, gradually over into the normal state. Many different methods have been elaborated with the view of achieving that task, which approach the subject from different points. As indicated in the introduction to this part, the older methods started by considering, in the first place, the forest as a whole, determining the yield, and then seeing in which parts of the forest it had best be cut. Moreover, working plans were prepared for long periods of time, usually a whole rotation. Gradually, a method was elaborated which considers, in the first place, the condition and requirements of each wood for a limited number of years, and adds up the operations thereby indicated. The sum of these cuttings represents the yield, but it is subject to a modification in so far as it would interfere with a sustained yield in the future. This method of determining the yield should be the basis upon which working plans should be prepared in all cases where a sustained yield is aimed at.

It is not possible, nor necessary, to deal in this chapter with all the numerous methods elaborated in the course of time; only those will be described which have been, or are likely to be, adopted.

SECTION I.—THE PRINCIPAL SYSTEMS.

1. The Regulated Selection System.

The selection system is the oldest of all systems. Originally, people selected the trees which suited their requirements and relied on Nature to replace what had been taken away. Probably the first attempt to control these operations was connected with the establishment of what are now called "protection forests," that is to say, areas which must be maintained under forest for the sake of their indirect effects. Apart from such areas, the bulk of the forest in the world is still selection forest, and much of it has been reduced in value owing to insufficient protection and

control. As a consequence, many of the selection forests in Europe have been converted into the "uniform system" with a view to obtaining higher returns. It has, however, been recognised of late years that the returns from properly treated selection forests are not necessarily smaller than those from areas treated under the uniform system. This has lead to a considerable improvement in the management of many of the remaining selection forests, which will now be described.

a. Description of the System.

Character of the System.—All size or age classes from one year old plants to the oldest trees are represented by single trees or

Fig. 58.—Selection Forest. (Conventional Sketch.)

small groups in all parts of the forest, and, theoretically, the work of selecting trees for cutting extends at all times over the whole forest. In practice, however, the forest is divided into a number of blocks, or compartments, which are taken in hand in turn for treatment, so that the cuttings return to the same part after the lapse of several years, called a "period." The size of the compartments and the length of the period depend on the intensity of management. The greater the intensity, the smaller will be the compartments and the shorter the period. The natural regeneration of the forest is effected under and between the shelter of the old crop, especially where single trees or small groups of trees have been removed.

If natural regeneration fails, artificial sowing or planting is not excluded, though it is required only in exceptional cases.

Preservation of Fertility.—The system secures at all times an equal degree of protection to the soil, more especially as regards the preservation of a suitable degree of moisture. Protection is given not only from above, but there is also side shelter, owing to the mixture of the several size classes in all parts of the forest. On sloping ground the rainfall is effectively retained ; avalanches, the carrying away of fine earth, landslips, etc., are prevented or at any rate moderated. As a consequence, protection forests situated in mountainous districts are usually managed under this system. All these matters act beneficially upon the producing factors of the locality, which is a substantial offset against any shortcomings of the system in other respects.

External Dangers.—Views differ somewhat regarding the extent to which selection forests are exposed to external dangers, as compared with the more uniform shelterwood systems. In the author's opinion, the selection system is, on the whole, the more favourable of the two, because only very small areas are at one time exposed to the injurious effects of the sun and unfavourable air currents. Damage by frost and drought is less, and probably also that from wind- and snow-break.

The Production of Wood.—Owing to the conversion during the last century of considerable areas of selection forests into the uniform systems, comparative observations are somewhat scarce. These conversions were due to the belief that selection forests produce smaller quantities of wood than the uniform systems. It has, however, been recognised of late that this opinion was due to the fact that many selection forests were not managed as efficiently as should have been the case. At any rate, there are now some selection forests which, owing to careful and rational treatment, are giving returns which are, as regards volume production, equal, if not superior, to the uniform shelterwood systems. Young growth, no doubt, develops slowly, as it is much kept back by the older trees, but this is made good by more active development when it has reached the full enjoyment of sunlight and the benefit of more favourable moisture conditions secured by the continuous protection of the soil.

The Quality of the Timber.—There can be no doubt that in many cases the boles of the trees produced under the selection system are less clean of low branches than those grown under the uniform

shelterwood systems. In the case of some species, the trees are also liable to suffer in height growth. These are, no doubt, shortcomings. On the other hand, the system is well suited for the production of trees with a large diameter, or girth, as the trees can be left in the forest for any length of time.

b. The Management of Selection Forests.

There cannot be any doubt that the successful treatment of selection forests depends more on the *individual efficiency* and zeal of the forester than is the case in any other system. To obtain really good results, it is essential that the forester should have a detailed knowledge of all parts of the forest, as he has, so to say, *to guide each promising tree throughout all stages of its life.* All depends on his personal judgment in the selection of the trees to be left for further development, of those to be cut, and of the time of removal. It follows that the forester must be given great freedom of action, and yet his measures must fit into the framework of a general scheme of management whenever a sustained yield is aimed at. Given such a manager, all will be well, but, failing this, mischief may be the consequence. There has been a protest of late against all kinds of control of the local managers, and a demand for full liberty. These are ideas which are not followed in other branches of human activity, and they are certainly out of place in forestry, where forethought for future requirements during long periods of time is essential.

The details of a general working scheme depend on local conditions, but the following may serve as an illustration :—

c. Determination and Regulation of the Yield.

The *first* and important measure is to divide the forest into a suitable number of compartments. The size of these depends on the total area of the forest and on the intensity of management. Where the latter is well advanced the compartments should be small, say not more than 50 acres. In the case of extensive areas it may be desirable to arrange the compartments into two or more working sections, and the compartments in each working section should be consecutively numbered—that is to say, one series of

numbers for each working section, and still better for the whole forest, unless it is of very large extent.

The *second* measure should be to treat each compartment on its own merits, with due reference to the yield of the whole section. If by careful treatment each compartment is gradually brought to its highest possible production, all must be well in the whole forest.

The *third* measure should be to ascertain the exact condition of each compartment, and from that date to keep a separate account for each unit of division of all measures taken and acts done within its boundaries. The establishment of sub-compartments should be reduced to a minimum. If they are of a temporary nature, they will naturally disappear in course of time. If a permanent distinction of part of one compartment is necessary, it is much better to establish two compartments at once instead of sub-compartments.

With a view to determining the *yield capacity* of each compartment and to lay down its further treatment, the growing stock, or stand, must be carefully measured and classified. The latter may differ in accordance with local conditions, but generally it would be somewhat on the following lines : All trees down to a minimum diameter (or girth) would be carefully measured, and their volume ascertained. These trees with their volume would be divided into several classes ; in some cases into large, medium, and small trees ; in other cases more distinct limits are adopted. For instance, let the minimum diameter at height of chest be 6 inches (or 20 inches girth) and each class comprise a range of 6 inches ; there would be the following size classes : First class = 6 to 12 inches ; second class = 12 to 18 inches ; third class = 18 to 24 inches ; fourth class = 24 to 30 inches, and so on. By numbering the classes in this way, the number of each class at once indicates its limits. Unfortunately, the reverse method of numbering from the largest class downwards has been much adopted. All young growth below 6 inches diameter is examined, so as to ascertain whether it is of sufficient quality to assure the required number of saplings to replace the larger trees which will be removed from time to time ; if not, suitable cultural measures must be adopted.

Throughout all stages of treatment the *yield* must be intimately connected with the *increment*. The one must be equal to the other

in all cases where the proportion between the classes is such that the objects of the proprietor can be indefinitely realised ; in other words, if the growing stock is normal. If there is either a deficiency or surplus of growing stock, in the one case less and in the other case more, then the actual increment should be cut, as a temporary measure, until the normal condition has been established.

The difficulty is to ascertain the actual increment at starting. An effort may be made to determine it by examining the increment of the immediate past and adopting that for the immediate future, until more reliable data become available. The latter can be obtained only by remeasurements after short intervals of, say, 5, 10, or n years. Let the volume in the beginning be V_1, that after n years V_n, and the volume removed during the n years $= Y_p$ ($p =$ periodic), then the increment during the n years amounts to $I_p = V_n + Y_p - V_1$. In this way the increment for the whole compartment can be ascertained, as well as for each class of trees. With every succeeding periodic measurement, the determination of the increment becomes more and more accurate.* In cases where the degree of intensity of treatment is very high, the investigation of the increment may be extended to single trees.

It is not possible to define the normal condition of the growing stock by a formula, as can be done in other systems. It can only be described as that which yields permanently the greatest return of the class of timber desired by the proprietor. The normal state can, as a rule, be reached only gradually in the course of several periods, during which the forester establishes the proper proportion between the several size classes, each consisting of vigorous promising trees. Their numbers should be such that each tree is given enough growing space required for full development and no more, according to the size class to which it belongs, and the light required for the proper development of young growth. With this reservation, a full stocking of the area should be aimed at, so as to obtain a full return, and to produce as clean and well-shaped boles as may be possible under the existing conditions.

* Several methods have been developed in India by Messrs. S. H. Howard, E. A. Smythies and others, which are very ingenious, but complicated, nor are they free from uncertainties. In the author's opinion, the above method is the only way of determining the increment accurately.

The procedure had better be further explained by a small example.

Example.—Given a selection forest of 300 acres which has been divided into 10 compartments of an average size of 30 acres each. Taking one of these compartments, it was found to contain a young growth below 6 inches diameter fit to furnish the several classes above 6 inches with a sufficient number of recruits. These classes contained at starting the numbers of trees and their volumes given in columns *b*, *c*, and *d* of the appended table :—

Number and Limit of Class. Diameter, Inches.	At Starting, per Acre.			After 10 Years (End of I. period) per Acre.					
	Number of Trees.	Average Volume per Tree. Cubic Feet	Volume Total. Cubic Feet.	Number of Trees.	Volume Total Cubic Feet.	Volume of Cut Trees. Cubic Feet. During 10 Years.	Total Volume. Cubic Feet. $f+g$.	Less Volume at Starting. Cubic Feet.	Increment during 10 Years. $h-i$.
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*
I. = 6—12	90	10	900	90	900	200	1,100	900	200
II. =12—18	40	25	1,000	41	1,025	400	1,425	1,000	425
III.=18—24	15	60	900	21	1,260	120	1,380	900	480
IV. =24—30	5	140	700	9	1,260	140	1,400	700	700
	150	..	3,500	161	4,445	860	5,305	3,500	1,805

This is the growing stock present at the commencement of the first period of, say, 10 years. It is proposed to remeasure the stock at the end of the 10 years, so as to obtain the data necessary for the determination of the periodic increment. As it is not desirable to suspend cuttings during the first period, nor to overcut the compartment, the forester must make the best estimate he can of the probable increment during the first 10 years. In some cases he may obtain sufficient information from adjoining forests to formulate his estimate. Failing this, he will probably attempt to ascertain the average increment laid on during the last 10 years by examining average-sized test trees of the several age classes. Assuming that he estimates it at 1,200 cubic feet per acre, and that a similar increment may be expected during the next 10 years, this quantity may be cut during the first period. But there is another consideration—namely, the present proportion of the volume in the several size classes. It will be observed that the two older classes contain only 1,600 cubic feet, against 1,900 in

the two younger classes. This is out of the proper proportion, as the former should contain at least half the total volume. In these circumstances, it is desirable to reduce the yield somewhat—say, to 800 cubic feet during the first 10 years—so as to provide, at any rate, some additional trees in the oldest age class. At the end of the first period it should be considered whether a further addition to that class is desirable. If the proportion between the several size classes is not governed by the objects of the proprietor, the most desirable proportion would probably be that which exists if each size class occupies the same area ; in the above example, 75 acres, less the area which must be allowed to give to the young growth under 6 inches diameter the necessary light for proper development.

The compartment, having been managed on these lines, is remeasured at the end of 10 years, when, it is assumed, it contains the stock shown in columns *e* to *j* of the above statement. The latter shows that the increment during the 10 years amounted to 1,805 cubic feet per acre. This is the maximum amount to be cut during the second period of 10 years. Whether the full amount is to be cut, or whether a further augmentation of the growing stock is desirable, depends on the experience gained during the 10 years. In this way, by repeated periodical measurements, the forest will gradually be brought into the condition of realising the objects of the proprietor to the fullest extent.

There can be no doubt that some remarkable results have been obtained by the adoption of the regulated selection system. Returns well over 100 and up to 150 cubic feet per acre and year have been shown in several cases, as, for instance, in the Oberwolfach communal forest and in the Schifferschafts forests of Forbach, both in the Black Forest ; in Neuchatel in Switzerland and in other forests of the Jura. More comparative experience is, no doubt, required before a final judgment of the system is justified, but in the meantime foresters will be well advised to pay careful attention to it. Its great assets are the continuous protection of the soil and the preservation of a suitable degree of moisture. The drawback is the more branchy nature of the trees in the older classes, though this can be somewhat reduced by the pruning of the lower branches while they are still small. The pruning should be done in instalments, beginning at a comparatively early age

with, say, the lowest 10 to 15 feet of the bole and carrying it up the tree by similar stages as the tree increases in height. The operation is, no doubt, expensive, but very good results have been obtained by it in the Oberwolfach communal forest. The expense can be reduced by restricting the pruning to the trees which will remain to reach the largest class.

It has been claimed that the system is applicable to all species, but that view cannot be accepted. It is suitable for shade-bearing and perhaps moderately shade-bearing species, while decided light-demanding species could not be naturally regenerated unless the older trees are placed so far apart that the principal advantage of the system, the protection of the soil and the preservation of a suitable degree of moisture, would be seriously reduced.

2. Brandis' System.

(Sometimes called the Indian System.)

A Modified Selection System.

There are as yet many forests on the earth containing a mixture of many species of which only one or a few are of value. For such forests a modified selection system is required, and one of the kind was evolved by Sir Dietrich Brandis soon after his appointment as superintendent of the Pegu teak forests in Burma, in the year 1856. These forests contained teak in varying proportion, which has since been found to amount to about 10 per cent., while the other 90 per cent. of the growing stock consisted of species which, at that time, were of no value. The latter were allowed to be removed free of charge without let or hindrance. As to the teak trees, the minimum marketable size was fixed at 6 feet girth measured at 6 feet from the ground ; these were called I. class trees.

Brandis was anxious to ascertain as quickly as possible the number of first-class trees which might be removed annually without endangering a sustained yield in the future. For this purpose, he ascertained :—

(1.) The number of I. class teak trees in the forests, and

(2.) The time which it takes to replace them.

By dividing the number of I. class trees obtained under (1.) by the number of years obtained under (2), he ascertained the

maximum number of trees permissible to be cut annually. Brandis fixed the annual yield accordingly, and thereby saved the valuable teak forests of Lower Burma from destruction. He allowed, however, a temporary increase if he found an excess of I. class trees.

Various safeguards were added, such as an allowance for trees which it did not pay to extract; where few second- and third-class trees existed, some first-class trees were left standing to provide seed for regeneration; immediately along the banks of streams cuttings were made very sparingly, etc.

For the rest, the method leaves a free hand to the forester, who arranges the cuttings with due regard to silvicultural requirements and a proper succession of the different coupes.

The numbers of trees of the several size classes were originally ascertained by counting, or measuring, them along narrow strips, generally 100 feet broad, laid through the forest along the line of march (called "linear valuation surveys"). From the contents of these sample strips (or plots) the contents of the blocks, or forest, were calculated. The rate of increment was determined by counting the concentric rings on a sufficient number of stumps, thus ascertaining the average number of years which a teak tree takes to reach the limits of the several size classes.

The original method was subsequently further elaborated, so that the sample plots are now systematically arranged over the area, with the view of obtaining correct data for the number of trees in the several blocks of the forest. The cuttings based on these data were also localised: in other words, an area check was added to the calculated yield, so as to guard against over- or under-cutting.

The method does not claim to be theoretically quite correct, but it is correct enough wherever large areas have to be dealt with in a short time. It works expeditiously, and, if judiciously applied, prevents a deterioration of the forest. Had it not been for this method, the valuable teak forests of Lower Burma might have been exhausted before their sustained yield capacity had been ascertained. It is a method to be strongly recommended for adoption in countries where systematic forest administration is in its earlier stages, and where only a limited number of species are as yet of commercial value.

Example :—

This example is based upon data contained in the working plan for the East Yoma, Salsuwa, and Tindaw Reserves in the Thayetmyo Division of Burma, drawn up by Mr. A. Rodger, then Deputy Conservator of Forests.

The productive area of the forests amounts to 84,022 acres, divided into 51 compartments. Of these, one was counted out altogether, while at least two sample plots in each of the other 50 compartments were marked, and the trees counted according to size classes. On the basis of the data thus obtained, the contents of the forests in sound teak trees over 1 foot 6 inches girth were calculated. They were as follows :—

Class	I. over 7 feet	girth =	31,523
,,	II. 6 feet to 7 feet	,, =	18,114
,,	III. 4 feet 6 inches to 6 feet	,, =	42,768
,,	IV. 3 feet to 4 feet 6 inches	,, =	101,737
,,	V. 1 foot 6 inches to 3 feet	,, =	150,910

To determine the rate of growth, countings on 198 trees and logs were made, which gave the following averages :—

Girth.		Age in Years.	Years required to pass through each Class.
1 foot 6 inches	..	31	
			. . 29
3 feet	..	60	
			. . 33
4 feet 6 inches	..	93	
			. . 37
6 feet	..	130	
			. . 26
7 feet	..	156	
			125

Hence, the rotation was fixed at 160 years, and divided into five periods of 32 years each.

From observations made in this and other forests in Burma, it was ascertained that the following percentages of sound trees are likely to survive and be available for utilisation :—

Class	I. over 7 feet	girth =	95 per cent.
,,	II. 6 feet to 7 feet	,, =	85 ,,
,,	III. 4 feet 6 inches to 6 feet	,, =	70 ,,
,,	IV. 3 feet to 4 feet 6 inches	,, =	50 ,,
,,	V. 1 foot 6 inches to 3 feet	,, =	25 ,,

giving the following numbers of trees available for utilization :—

Class	I. =	29,947	
,,	II. =	15,397	133,932.
,,	III. =	29,938	
,,	IV. =	50,869	
,,	V. =	37,728	
	Total	163,879	

As it requires 125 years to pass a tree of 1 foot 6 inches girth into the first class, the average number of trees passing annually into the first class would be $\frac{133,932}{125} = 1,071$ trees a year.

There is evidently a surplus of trees over 7 feet girth, as it is not necessary to keep more than half the average yield of a period of such trees standing in the forest, or $1,071 \times 16 = 17,136$. The balance, $29,947 - 17,136 = 12,811$ trees, might be removed in addition to the actual increment. Assuming that the surplus of growing stock in the first class were removed during the first period of 32 years, or 400 trees annually, the theoretically correct yield would amount to :—

Yield representing the annual increment	=	1,071 trees
,, ,, removal of surplus stock	=	400 ,,
Total permissible yield, annually	=	1,471 trees.

As a rule, it is desirable, for other reasons, not to work up to the full theoretical yield. On the one hand, certain trees never reach a girth of 7 feet, while, on the other hand, trees of 8 or 9 feet girth yield much higher prices per cubic foot than smaller trees. In many cases, some mature trees must be left standing to provide seed for regeneration. Hence, the actual yield has, in this instance, been fixed at 1,000 trees annually, for a term of 32 years.

3. Division of the Forest into Fixed Annual Coupes.

Under this method the area of the forest, or working section, is divided into as many annual coupes as there are years in the rotation, and each coupe is marked on the ground. Every year one coupe is cut over, giving the annual yield of final returns, to which must be added the necessary thinnings in the other coupes. The size of each annual coupe is $= \frac{A}{r}$ if the area is at once restocked, or $= \frac{A}{r + s}$ if each coupe lies fallow for s years. In either case, the area of the coupes should be so fixed that all have the same yield capacity (see page 245).

The system was introduced into French and German State forests about the middle of the eighteenth century.

The merits of this method are small. It aims more directly than any other method at the establishment of a regular series of age gradations, which becomes normal after one rotation if the division of the area is based upon the reduced area of the several parts. It achieves this object only by heavy sacrifices, because

the returns during the first rotation must be very uneven, unless at the outset a proper proportion and distribution of the age classes existed. The method takes no notice of disturbances, nor of the state of the market ; hence, it is very rigid. Above all, it neglects to a considerable extent the fundamental principle that the most important measure must always be the establishment of the normal increment within the shortest possible period of time.

The method is applicable to coppice woods, coppice with standards, and, with modifications, to selection forests ; for all other methods of high forest it is unsuited, except perhaps for clear cutting with a short rotation.

4. Allotment of Woods to the Different Periods of one Rotation.

In order to remove the great rigidity of the fixed annual coupes, and to obtain a method which is suitable for the treatment of high forest, especially if managed under one of the shelterwood systems, the several woods comprising a forest are allotted to a number of periods. The latter are generally from 3 to 6 in number, and each contains from 10 to 30 annual coupes. In this way, the forest is divided into as many lots as there are periods in the rotation ; during each period one of these lots is dealt with. Thus, operations extend over the whole area once in each rotation. Deviations from this arrangement occur occasionally—for instance, if a sub-compartment is not cut over, or twice cut over, during the first rotation, in order to make the compartment uniform.

It is evident that during the first rotation the total yield is represented by the growing stock which happens to stand in the forest at the commencement of operations, plus that part of the increment which is added to it during the course of the first rotation ; it may be equal to, smaller or larger than, the normal yield.

An essential part of this method of regulating the yield is the preparation of a framework or general working plan, drawn up for one rotation and divided into a number of periods, showing during which period each wood is to be cut over. The allotment can be made according to area, volume, or the two combined, so

that practically three different methods exist, which must be described separately.

The regeneration of the woods placed in each period can be effected by clear cutting and planting, or by natural regeneration under a shelterwood.

a. The Method of Periods by Area.

(First developed by H. Cotta in Saxony early in the nineteenth century.)

The woods of a forest are so allotted to the several periods of one rotation that each contains the same or approximately the same area, called the "periodic coupe."

Where few or no differences exist in the quality of the locality in the different parts of the forest, the size of each periodic coupe will be $= \frac{A}{t}$, where t represents the number of periods in the rotation. If differences exist, the areas must be reduced to one common quality standard, and the size of the periodic coupe becomes $= \frac{\text{red. } A}{t}$. Unless this is done, the periodic yields in the second and following rotations will not be equal.

In allotting the woods to the several periods, that to be dealt with first receives the oldest woods and those with the most deficient increment, taking into consideration a suitable arrangement of the cutting series ; the allotment to the other periods is made according to the age of the woods, with due consideration to a suitable grouping of the age classes. If the totals in the several periods differ, shiftings are made by moving certain areas backward or forward, until each period contains the same or approximately the same area.

The woods placed into the first period are measured, their volume calculated, and the increment for half the number of years in the period, $\frac{n}{2}$, added. The total of the volume thus obtained is divided by the number of years in the period n, so as

to obtain the average of the final annual yield during the first period. To this amount the thinnings must be added.

For an example, see Appendix V., A,, where the working plan for the communal forest of Krumbach, a village in Hesse-Darmstadt, is given. This working plan has been actually followed.

The method is simple and can be applied by any intelligent manager. It establishes the normal state within one rotation, if no disturbing events occur. At the same time, it may yield uneven returns during the first rotation, though this can to some extent be avoided by suitable shiftings. Although the method is much less rigid than that of fixed annual coupes, it is often difficult to produce during the first rotation a proper grouping of the age classes.

Another disadvantage is that a surplus of growing stock may be dragged over a whole rotation, whereas it should be removed as quickly as possible ; or, on the other hand, it may take a whole rotation to make good any deficit of growing stock.

The method gives only a limited latitude to the forester to hold over vigorous woods, or to cut over at an early date those which are deficient in increment. For a financial management, the method is only moderately adapted, except in so far that it introduces order into the management.

b. The Method of Periods by Volume.

This method was developed by G. L. Hartig during the end of the eighteenth and the beginning of the nineteenth centuries.

The woods of a forest are so allotted to the several periods of a rotation that each yields the same or approximately the same volume. In some cases, only the final returns are thus regulated ; in others, the intermediate returns are utilized to equalise the yields of the several periods.

The allotment is based upon the table of age classes ; then shiftings are made, so as to bring woods which have a poor increment early under the axe and establish, as far as practicable, a suitable grouping of age classes ; then further shiftings are made, so as to equalise the periodic returns. The result represents the general working plan for the first rotation. It will be found that, in the majority of cases, the areas placed in the several periods

will be uneven, resulting in uneven returns during the second rotation, unless a fresh allotment is made.

Example.—In Appendix V., B., only the final returns have, for simplicity's sake, been equalised. The data are those of the Krumbach communal forest given in Appendix V., A.

As the future returns have to be estimated for a whole rotation, it is evident that yield tables must be used; accordingly, the above general working plan has been based upon the returns for beech high forest, given at page 361. After making the shiftings indicated in the general working plan, the volumes allotted to the several periods stand as follows :—

	Periodic Yield. Cubic Feet.	Annual Yield. Cubic Feet.	Area in the Period. Acres.
Period I.	= 201,740	10,087	34·0
„ II.	= 207,421	10,371	32·5
„ III.	= 210,932	10,547	30·5
„ IV.	= 206,180	10,309	30·0
„ V.	= 212,286	10,614	33·0
Total	= 1,038,559		160·0
		Mean periodic area =	32·0

An attempt to equalise the returns further would necessitate the cutting up of compartments, which is not desirable.

The areas placed in the several periods are uneven, and fresh shiftings may have to be made later on, so as to equalise the returns during the second rotation.

The method has this advantage over the method by area, that it gives during the first rotation equal or approximately equal periodic returns; it considers the interests of the present generation more fully. On the other hand, the estimate of the future returns is more or less problematic, so that the equalisation of the returns for a whole rotation ahead is a very uncertain operation. It shares with the method by area the disadvantage that a proper grouping of age classes is generally beset by difficulties. It may also drag a surplus or deficit of growing stock over a whole rotation.

Whereas the method by area establishes the normal state of the forest within one rotation, the method by volume generally takes several rotations to accomplish this, but the difference from the normal state is very small by the end of the first rotation.

As regards its financial aspect, it stands on about the same footing as the method by area.

c. The Method of Periods by Area and Volume Combined.

The woods of a forest are so allotted to the several periods of a rotation, that each contains the same area and yields the same or approximately the same volume.

The equalisation of the periodic areas and returns is effected, either by adding columns for the volume to the general working plan used for the method by area, or by adding columns showing the reduced areas to the general working plan used for the method by volume. Shiftings are made until both area and yield are the same or approximately the same in each period. It will be easily understood that such an equalisation is a difficult operation, especially in a very abnormal forest; hence, more than an approximate equalisation cannot be attempted.

The method shows some of the advantages and disadvantages of the two previous methods of which it is a combination. Its principal disadvantage is that a suitable grouping of age classes is still more difficult than in the case of each of the two component methods.

In practice, various modifications of the above three methods have been evolved which sometimes partake more of one and sometimes more of another of the methods.

THE FORMULA METHODS.

The next four methods, numbers 5, 6, 7, and 8, determine the yield by a formula, based on the increment laid on and any difference between the real and normal growing stock. Having thus ascertained the yield, the woods for cutting during the next period are selected in accordance with silvicultural considerations and other requirements. No provision is made in them for the drawing up of a general plan of operations for a longer period than suits the special requirements of each case. Of a considerable number of methods coming under this heading, only the four mentioned above need be described here; the others are either modifications of these, or of limited practical value.

5. The Austrian Assessment Method.

In the year 1788 (during the reign of the Emperor Joseph II., one of the most enlightened sovereigns known in history) the

Austrian Government issued instructions regarding the assessment of forests for the purpose of taxation. In these instructions reference was made to the difference which may exist between the real and normal growing stock of a forest. This led to the knowledge that a forest, which is expected to give permanently an annually equal return of the normal age and amount, must contain the normal growing stock corresponding to the rotation and method of treatment. Foresters speedily applied this principle to the regulation of the yield of forests by saying that, in order to lead an abnormal forest over into the normal state, it is necessary to establish the normal growing stock—in other words, to remove a surplus or to save up any deficit, as the case might be. The method developed upon this basis is called the "Austrian assessment method." Authors differ as to the details of the original method, but a general survey of the literature on the subject gives the following rule for determining the yield :—

"If the normal growing stock is present in a forest, then the actual, or real, increment must be utilized ; if the real growing stock is greater than the normal, more than the real increment must be removed for a time ; if the real growing stock is smaller than the normal, less than the real increment should be utilized, until the deficiency has been made good."

In carrying this excellent idea into effect, however, errors were introduced, which are still upheld by some foresters of the present day.

The procedure is described as follows :—

(1.) The increment is calculated as the mean annual increment of a series of years.

(2.) The normal growing stock is placed equal to the *normal* final mean annual increment, corresponding to the normal rotation, multiplied successively by the ages of all age gradations ; the sum of all these products gives the value $G_n = I \times \frac{r}{2}$, calculated for the middle of the growing season. Here I represents the normal annual increment of all age gradations, which is equal to the volume of the oldest age gradation.

(3.) The real growing stock is obtained by multiplying the *real*

final mean annual increment by the present age of each age gradation. For this purpose it is necessary to determine for each wood the real final age and the volume at that age.

(4.) The difference between the real and normal growing stock is removed during such period as the owner, or forester, may determine according to the circumstances of each case, more especially the conditions of the market.

(5.) The general formula for calculating the yield, if the deficiency or surplus of growing stock is to be removed in the course of *a* years, runs as follows :—

$$\text{Annual Yield} = \text{real Increment} + \frac{\text{real Gr. Stk.} - \text{norm. Gr. Stk.}}{a}$$

$$Y = I_{real} + \frac{G_{real} - G_{normal}}{a}.$$

If $G_r < G_n$, then the last position becomes negative.

The method was the first which based the calculation of the yield upon a knowledge of the increment and the growing stock. It has the advantages over most other methods that :—

(1.) It teaches the proportion between the real and normal growing stock and enables the owner to remove any surplus or deficiency at his pleasure.

(2.) It assures to the owner the utilization of the full real increment, whenever the normal growing stock is present.

(3.) It distinguishes in the yield between increment and growing stock ; in other words, between the removal of genuine annual increment and that of surplus capital.

On the other hand, the method, as above described, has serious drawbacks :—

(1.) The calculation of the real and normal growing stock, based upon the final mean annual increment, is not correct and not even safe. As, however, both are calculated in the same manner and one is deducted from the other, the error is to some extent eliminated.

(2.) As the yield is determined by a formula, the method, if rigidly applied, may lead to absurd results : for instance, it may happen that a full increment takes place, that numerically the real growing stock is equal to the normal

growing stock, and yet there may not be a single mature wood in the forest available for cutting.

The method is, however, one of considerable merit, provided it is somewhat modified, that is to say, if :—

(1.) The real growing stock is taken as that actually existing in the forest, and the normal growing stock is calculated from a suitable yield table.

(2.) The yield as calculated with the formula is modified to suit the special conditions of each case—in other words that final cuttings are reduced, or even suspended for a time, if the area of mature woods is below the normal amount.

The method gives to the forester full liberty to arrange the cuttings in accordance with the silvicultural requirements of each wood, and to arrange the grouping of the age classes and cutting series in the most desirable way.

The method is applicable to all silvicultural systems, but the determination of the increment involves much labour, if it is to be accurate. Under it a forest is gradually lead over to the normal state, though perhaps not for a considerable time ; the difference between the real and normal state will be very small at the end of the first rotation.

The sample working plan given in Appendix VI. is based upon the formula of this method. The plan has actually been carried out in a part of the Herrenwies Range in Baden.

6. Heyer's Modification of the Austrian Method.

This method was originally designed by Carl Heyer ; it rested on the Austrian method. Subsequently it was further developed, especially by Gustav Heyer, until it became a combination of the Austrian method and the allotment of woods to periods by area. It is generally known as "Heyer's method."

Its theory is as follows :—

(*a.*) To arrange all woods into a general working plan according to periods, so that each period contains the same or approximately the same area. The object of this arrangement is to equalise the increment during the second and subsequent rotations.

(*b.*) To equalise the real and normal growing stock, if any

difference should exist, in such manner and within such time as may be indicated in each case and approved by the owner.

(*c.*) To utilize the real increment, calculating the mean for a series of years, plus or minus the quota of growing stock determined under (*b*).

It is obvious that these objects can be realised only by a complicated procedure, and even then only approximately, because changes in one direction disturb the balance in another.

Practical Application of the Method.

(*a.*) The first step is to allot, by means of the table of age classes, all woods to the several periods, and to equalise the areas by suitable shiftings, as indicated under the method of periods by area; care being taken to allot the woods, as far as this is practicable, with due consideration to silvicultural requirements, and a proper distribution of age classes.

(*b.*) The real increment is placed equal to the real final mean increment, for which purpose it is necessary to determine the final age of each wood (which may differ from the normal final age) and its probable volume at that age; the latter divided by the former gives the mean annual increment. In order to avoid having to calculate the increment year by year, it is generally calculated for a number of years, which may be called a'. If an abnormal wood is cut over during the a' years at an age differing from the normal, and a normal wood grows up in its place, the increment must be calculated separately for each part of a' years.

(*c.*) The normal and real growing stocks are calculated as for the Austrian method; the former is placed $= \frac{I \times r}{2}$, where I represents the normal final mean increment; the latter is obtained by multiplying the real final mean increment of each wood by its age. The difference between the real and normal growing stock is removed as may be approved by the owner, say in equal amounts in the course of a years.

(*d.*) The theoretical yield is then fixed by the formula—

$$Y = \frac{\text{Real Increment of } a' \text{ years}}{a'} + \frac{G_{real} - G_{norm.}}{a}.$$

If a' is placed equal to a, that is to say, if the real increment is calculated for the number of years during which any difference between the real and normal growing stock is to be removed, the above formula goes over into—

$$Y = \frac{G_{real} + Ia_{real} - G_{norm.}}{a}.$$

(*e.*) The next step is to ascertain, whether the woods preliminarily placed in the several periods are sufficient to meet the yield during each period as calculated by the formula under (*d*), or whether they contain too much or too little volume ; in the latter case, suitable shiftings must be made which necessitate, of course, fresh calculations of the increment and real growing stock, as the final ages of some of the woods are thereby altered. This process is continued until the requirements of the method are realised, that is to say, until each period contains the same area, and at the same time the volume necessary to meet the yield as calculated under (*d.*) As already indicated, the forester must, in this respect, be satisfied with approximate results.

(*f.*) The regulation of the yield is restricted to final returns. The intermediate returns are estimated only for the first period, or part of it, by means of yield tables, or past experience, and added to the final yield.

The method is one of great precision. On the other hand, it is very complicated, and it calculates the increment, as well as the normal and real growing stock, incorrectly, as in the case of the Austrian method. The latter objection could be removed by using suitable yield tables, instead of the final mean annual increment, for the calculation of the increment and normal growing stock, and by measuring the growing stock actually standing in the forest. Nevertheless, the method involves great labour, and the necessary calculations are of an uncertain nature.

7. Hundeshagen's Method.

Hundeshagen's method of determining the yield is based upon the idea that the real yield must bear the same proportion to the real growing stock as that existing between the normal yield and normal growing stock ; he thus obtains the equation—

$$Y_{real} : G_{real} = Y_{norm.} : G_{norm}$$

and

$$Y_r = G_r \times \frac{Y_n}{G_n}.$$

In words, the real yield is equal to the real growing stock multiplied by the normal yield and divided by the normal growing stock. Hundeshagen calls the quotient $\frac{Y_n}{G_n}$, by which the real growing stock is multiplied, the "utilization per cent." (More correctly this indicates only the rate of utilization, whereas the utilization per cent. is $\frac{Y_n}{G_n} \times 100$.)

The normal yield is placed equal to the normal increment, or equal to the contents of the oldest age gradation in a normal series of age classes. The normal growing stock is obtained by adding up the volumes given in a suitable yield table ; by the real growing stock Hundeshagen understands that which is actually standing in the forest.

In applying the method, Hundeshagen prepares a general working plan, for a limited number of years ; he determines the species, silvicultural system, general lines of management, the rotation and general rules for the grouping of the age classes ; he leaves it to the manager to select the woods for cutting from time to time, say every 5 or 10 years.

As the yield is determined by the growing stock which happens to exist, and as this practically changes from year to year, it would, theoretically speaking, be necessary to remeasure the growing stock every year, but, as the changes are slow, Hundeshagen considers it sufficient if the remeasuring is done once every 20 or 30 years.

Hundeshagen determines, in the manner above described, only

the final returns ; he adds the intermediate returns, estimated in a summary manner, or calculated according to average data obtained locally.

The principal assumption of Hundeshagen is not quite correct ; at any rate, there is no justification for maintaining that the real yield bears the same proportion to the real growing stock as the normal yield to the normal growing stock, because the rate of increment is not determined by the quantity of growing stock which stands in a forest. On the contrary, a large growing stock consisting of defective old woods may give a small increment, while a small growing stock consisting of vigorous young woods may show a large increment.

The method, if applied rigorously, may lead to absurd measures, just in the same way as the original Austrian method ; it prescribes a definite annual yield, while not a single mature wood may be present ; or it prescribes too small a yield, whenever a considerable portion of the area is stocked with decrepit old woods which ought to be cut over as quickly as possible and replaced by vigorous young woods. In all such cases, the yield, as fixed by the formula, must be modified in accordance with the requirements of each case.

The method does not distinguish in the yield between increment and surplus growing stock, and in this respect it stands below the Austrian method. Moreover, it may drag a surplus of growing stock over an undefined period.

Hundeshagen assumes that, with the yield calculated according to his method, the normal growing stock will be established automatically, as the yield bears a fixed proportion to the real growing stock ; if the latter is greater than the normal amount, more than the increment will be removed, and *vice versâ*. This is ordinarily the case, but not in all circumstances. If, for instance, both the increment and growing stock are deficient, the yield may be greater than the increment, so that the growing stock is still further reduced, at any rate for a time ; hence, the establishment of the normal state may be considerably delayed.

On the other hand, Hundeshagen's method has this great advantage, that the increment need not be determined, such an operation being at all times beset by difficulties and uncertainty. All that the method requires is a suitable yield table, and

the measurement of the growing stock actually standing in the forest. Hence, the method is by no means to be despised, if a general plan is added indicating the grouping of the age classes to be aimed at. For the rest, it leaves a free hand to the manager to shape the management in accordance with the requirements of each case, as long as the yield determined by the formula need not be rigorously cut. It may reasonably be assumed that Hundeshagen himself expected this.

8. von Mantel's Method.

Von Mantel, in arranging for the speedy determination of the yield of certain forests in Bavaria, laid it down that this should be done according to the formula—

$$\text{Annual Yield} = \frac{\text{Real Growing stock of the forest}}{\text{Half the number of years in the rotation}} = \frac{G_{real}}{\frac{r}{2}}.$$

It is based on the assumption that approximately twice the growing stock is removed in the course of each rotation, as has been mentioned above.

This formula rests upon the same basis as Hundeshagen's method, if for the latter the normal growing stock is calculated with the final mean annual increment as in the Austrian assessment method. Hundeshagen's formula—

$$Y = G_{real} \times \frac{Y_n}{G_n}$$

in that case goes over into—

$$Y = G_{real} \times \frac{I_n}{I_n \times \frac{r}{2}} = \frac{G_{real}}{\frac{r}{2}}.$$

The cutting of the yield according to von Mantel's formula will gradually lead to the establishment of the normal growing stock, as the following considerations will show :—

Supposing the real growing stock, by which von Mantel under-

stands that actually present in the forest, is equal to the normal growing stock, then his formula goes over into—

$$Y = \frac{\frac{r \times I_n}{2}}{\frac{r}{2}} = I_{norm.}$$

The formula gives, therefore, the correct yield, provided the increment is normal.

If the actual growing stock is smaller than the normal, say

$G_{real} = \frac{r \times I}{2} - x$, then

$$Y = \frac{\frac{r \times I}{2} - x}{\frac{r}{2}} = I - \frac{x}{\frac{r}{2}},$$

which means that less than the increment is cut.

Supposing that the real growing stock is greater than the normal: $G_{real} = \frac{r \times I}{2} + x$; then,

$$Y = \frac{\frac{r \times I}{2} + x}{\frac{r}{2}} = I + \frac{x}{\frac{r}{2}};$$

more than the increment will be cut, so that the surplus of growing stock will gradually disappear.

All these assumptions depend, however, on the supposition that the normal increment is laid on. If the increment is deficient, the abnormal state may be further increased until the increment has reached its normal size.

The merits of the method are approximately those of Hundeshagen's method. The normal growing stock and normal yield need not be determined; in other words, the method can do without yield tables. It is only necessary to measure the growing stock and to determine the rotation; hence, the method is very simple in execution.

9. The Compartment, or Uniform, System.

Selection of Woods for Cutting according to Silvicultural Requirements and the Objects of Management.

The system was developed by degrees in Saxony from Cotta's time onward, and put into a definite shape by Judeich. It is known as Judeich's "Bestandswirthschaft." By "Bestand" is understood a part of a forest of about the same description which ordinarily is treated in a uniform manner ; it may comprise a sub-compartment, or a compartment, or more than one compartment. The main character of the system is that each "Bestand," or wood, is treated on its own merits throughout its life, and that the yield of the whole forest represents the sum total of the returns prescribed for the several compartments (or other units of division).

In introducing the system, the first step is to divide the forest into a suitable number of compartments, including an appropriate system of roads and rides ; the latter need not be all constructed at once, but can be taken in hand as they are required by the progress of the work. In designing the system of roads and rides, special attention must be paid to a suitable arrangement of the age classes, both in size and grouping.

Next, each compartment is examined and its future treatment for a limited number of years indicated, with due consideration for its silvicultural requirements. The estimates of the projected final cuttings in the several compartments are added up, and they represent the final yield during the next, say, 10 years, unless considerations for a sustained yield in the future demand certain modifications.

The method aims chiefly at the establishment of a full increment and a proper arrangement of the age classes ; these given, the normal growing stock comes of itself. An important point is to determine the working only for a short period, and to improve it at each revision in the light of past experience. The requirements of each compartment can be reconsidered, and the establishment of the necessary cutting series developed. The latter point is of special importance in coniferous forests. It provides a sufficient number of points of attack, and gives the forester a free hand to deal with each wood at the right time.

If the area of the forest is considerable, or consists of pure woods worked under different rotations, the forest may be divided into two or more working sections. Each of these should be dealt with separately, and a special account kept of it.

The system is equally applicable to the method of clear cutting and to that of regeneration under a shelterwood.

a. Short Description of the Two Methods.

Under the method of clear cutting, the new wood is originated on an area clear of trees, by direct sowing of seed or by planting, or occasionally by seed coming from adjoining woods. The trees on each gradation are all of the same age and height, or nearly so. From the time when the branches begin to interlace, they form an uninterrupted leaf canopy overhead throughout life, favouring the formation of trees clear of branches to a considerable height. The extent of this depends on the original degree of density, the species, the quality of the locality and the degree of thinning. The effect of protection given by the wood to the producing factors of the locality differs with the age. During early youth, the soil is exposed to the full effect of the sun and air currents. Subsequently, when the leaf-canopy has been established, its beneficial effect is of a high degree, but when, with advancing age, the crowns have been elevated, air currents pass through the wood and may reduce the activity of the locality, chiefly through the loss of moisture in the soil (see Fig. 52, page 209). The clearings should be of moderate extent, and one should not adjoin a previous one except after the lapse of several years. Frost, drought, insects and air currents are likely to do much damage during the early years of the wood. The production of wood compares favourably with that of other high forest systems, and the quality of the timber is of a high class, provided that the thinnings are carried out in a judicious way.

Under the shelterwood method, the wood is regenerated under the shelter of the whole or part of the old crop, which is retained until the new crop has established itself and is safe against injurious external influences peculiar to early youth. The regeneration is effected by the seed falling from the shelter trees, assisted, if necessary, by sowing or planting. In some cases the latter may

be done at once without waiting for a seed year. In many cases there is a difference in the age and height of the new crop, which, however, is no longer discernible by the time the wood has reached middle age. This system has the advantage over the clear cutting system in providing good protection to the young crop during early youth against frost and drought and, in many cases, also against insects. When once that period is passed there is practically no difference between the two systems. The shelter trees generally increase rapidly in diameter or girth, owing to their more open position ; on the other hand, the shelter trees are liable to be thrown by wind, and their ultimate removal frequently does some damage to the new crop.

b. *The General Plan of Operations.*

This plan gives the division of the forest into units of working, generally called compartments. They should be numbered consecutively—that is to say, by one series of numbers throughout each working section, if not throughout the whole forest. The compartments are marked off by natural or artificial lines, of which one at least should, if possible, abut on a road, or other means of transport. This plan enables the forester to determine, in a general way, the order and direction in which the cuttings should proceed, and the grouping together of compartments into suitable cutting series, especially in the case of clear cuttings. In some cases, temporary cutting series may have to be designed which, at the time of revision, will be changed into more permanent groupings.

c. *Determination of the Rotation.*

The method of determining the rotation has been explained on pages 188 to 195. It differs from that followed by Judeich, who adopted the financial rotation for the Saxon forests. Experience has shown that short rotations, in connection with clear cutting, lead to a reduction of the yield capacity of the locality, except on really fertile lands, and these are rarely placed at the disposal of the forester. The rotation should be fixed with due regard to local conditions and the class of produce which the proprietor desires to grow. At the same time, it is desirable to inform the proprietor of the temporary financial loss due to a departure from the

financial rotation. Such loss is, as a rule, in the long run, more than recovered by the maintenance, and even improvement, of the fertility of the locality.

d. Determination of the Final Yield.

The woods in which final cuttings during the working plan period are to be made should be selected with due consideration for the desired cutting direction and the establishment of suitable cutting series. No woods should be selected the removal of which would expose adjoining woods to damage by windfalls, unless they are also to be cut during the working plan period. Subject to these considerations, the following areas would be selected :—

(1.) Areas to meet silvicultural or other necessities, such as the establishment of severance cuttings, woods interfering with the establishment of a proper grouping of age classes or cutting series, proposed road lines, etc.

(2.) All decidedly ripe woods, as determined by the objects of management.

(3.) Woods the ripeness of which is doubtful, or which may be situated in the direction of the cuttings. This includes the woods which will become ripe during the working plan period.

The sum total of the cuttings indicated under these three headings represents the final yield to be assigned to the period for which the working plan is being prepared.

For small forests, or those where a sustained annual or periodic yield is not called for, nothing further is required. It is different in the case of extensive areas, especially those where considerations for a steady annual income, the regular supply of markets, or the occupation of the staff and workmen necessitate an approximately even annual out-turn. Here, the yield, as determined above, must be subjected to a *modifying regulator*, either as regards the area to be cut or the volume to be removed during the working plan period.

This regulator can take any suitable shape, such as the size of the mean annual or periodic coupe, or the yield calculated according to volume and increment, or both. Judeich prefers the mean annual coupe, as obtained by dividing the total area by the fixed rotation. If a forest has an area of 2,000 acres and is worked

under a general rotation of 80 years, the mean annual coupe would be equal to $\frac{2000}{80} = 25$ acres. During a working plan period of 10 years, the normal cutting area for it would amount to $25 \times 10 = 250$ acres. In other words, during a period of 10 years, 250 acres should be cut over or taken under regeneration, and the areas selected as indicated above should be brought within that limit. This, however, is desirable only if the proportion of the age classes is fairly normal. In all cases where considerable deviations from the normal proportion exist, such a narrow limit cannot be drawn, because in some cases it is highly desirable to deal with more than the normal area, if, for instance, too large a proportion of old or defective woods exists, or regeneration proceeds slower than expected. In other cases, the cuttings should be below the normal area, if, for instance, the area of mature woods is deficient. Hence, the regulator should give merely the maximum and minimum area or volume to be dealt with. In the above case, the area might be given as 200 to 300 acres, or corresponding volumes.

As long as the total area determined under (1.) to (3.) falls between these limits, it may be accepted as the area to be dealt with during the first 10 years. If it is larger than the maximum, then some of the most suitable areas enumerated under (3.) should be held over until the second period of 10 years ; if smaller than the minimum, then possibly some further woods may be found which could be added to those already placed under (3.). In extreme cases, the yield may be kept for a number of years below the proper minimum.

Example.—Let the age classes in the above example be as follows :—

Age Class.	Normal Distribution of Areas. Acres.	Real Distribution of Areas. Acres.	
1—20	500	400	700
21—40	500	300	
41—60	500	700	1,300
Over 60	500	600	
	Total = 2,000	2,000	

As there is a considerable excess of old woods, the area to be cut, or taken under regeneration, every 10 years should be more than $\frac{2,000}{8} =$

x 2

250 acres. Indeed, for the next 20 years up to 300 acres might be cut or placed under regeneration during every 10 years. The result would be as follows :—

Age Class.	After 10 Years. Acres.		After 20 Years. Acres.	
1—20	= 500	850	= 550	975
21—40	= 350		= 425	
41—60	= 500	1,150	= 425	1,025
Over 60	= 650		= 600	
	Total = 2,000		2,000	

After that, 250 acres might be put under regeneration during every 10 years, so that, at the end of 30 years in all, the distribution of the age classes would be :—

Age Class.		After 30 Years. Acres.	
1—20	=	525	1,012
21—40	=	487	
41—60	=	425	988
Over 60	=	563	
		2,000	

The deviations from the normal distribution still existing will disappear by continuing to cut about 250 acres every 10 years.

e. The Intermediate Yields.

The limit between final and intermediate yields is not always easy to define. In a general way it may be said that—

(1.) *Final yields* comprise—

(*a.*) All returns obtained from woods which are put down for regeneration during the first period.

(*b.*) All returns from other woods which, in consequence of unforeseen causes, are so large that the regeneration of the woods becomes necessary, whether it is done during the working plan period or later on.

(2.) *Intermediate yields* comprise all other returns derived from—

(*a.*) Cleanings.

(*b.*) Ordinary thinnings.

(*c.*) Pruning, cutting of standards, etc.

(*d.*) Accidental cuttings, such as dry wood cuttings, windfalls, etc., in so far as they do not occur in the areas

put down for regeneration during the working plan period, or are of such extent that they come under sub-head (1 *b.*), above.

The woods to be cleaned and thinned are put down according to their areas. The quantity of intermediate yields is best estimated according to past local experience, with due consideration of the condition of the several woods. Where the necessary local data are not available, the most suitable average data obtained elsewhere must be used, or an estimate made in accordance with the condition of the woods.

The question whether the regulation of the yield should refer to the final cuttings only, or include the intermediate cuttings, has been much discussed. There can be no doubt that the systematic working of a forest should, in the first place, be regulated by the final cuttings. At the same time, the intermediate yields may be utilized to equalise any unavoidable inequalities of the final yield. In any circumstances, both classes of yields must be estimated, so as to ascertain the probable quantities of produce which will be placed upon the market, and to prepare the annual budgets.

The total yield of the working plan period is suitably divided amongst the years comprised in it.

f. Separation of Yield into Classes of Produce.

The yield should be separated according to classes of produce as it is brought into the market, say as timber and firewood, or large timber, poles, mining props, faggots, etc., each being given in cubic feet. This separation should be based upon locally-obtained proportional figures.

It is also desirable to give separately the yield of the important species—as, for instance, oak, other broad-leaved species, larch, other conifers, etc. In India, teak, sāl, deodar, and some other valuable species should always be given separately.

g. Example.

Given an area of 4,000 acres stocked with spruce = 90 per cent., silver fir = 4 per cent., beech = 2 per cent., and blanks = 4 per cent. The latter are due to the necessity of allowing the cut areas to lie fallow for two years,

on account of the presence of pine weavils. The silver fir and beech are found over the whole area in single trees, so that the forest represents practically an almost pure wood of spruce. The forest has been divided into 100 compartments, with an average area of 40 acres each. As the work proceeds it is proposed to arrange these into 25 cutting series of an average area of about 160 acres (see Figure No. 53, on page 211). This arrangement will enable the forester to select at all times for regeneration those parts of the forest which are in the greatest need of treatment.

The age classes are represented in the following proportion :—

Age Classes.	Normal Area.	Actual Area.	
1—20	1,000	1,100	1,800
21—40	1,000	700	
41—60	1,000	800	2,100
Over 60	1,000	1,300	
Blanks	—	100	
Total area ..	4,000	4,000	

The local value of the soil was ascertained to be £10 per acre. An examination of the average height growth of typical woods showed that the soil must be classed as I. quality, to which the following normal yield table would apply :—

Age. Years.	Mean Height. Feet.	Mean Girth. Inches.	Yield in Cubic Feet, Per Acre.		Timber. Total.	Mean Annual Forest. Per Cent.
			Final.	Thinnings.		
30	51	23	3,500	410	3,910	2·4
40	66	33	5,250	925	6,175	3·7
50	80	42	6,760	960	7,720	4·0
60	91	50	8,020	860	8,880	4·1
70	100	56	8,960	665	9,625	4·0
80	106	60	9,400	500	9,900	3·9
	Total thinnings	..	..	4,320		

From the data given above, the mean annual forest per cent. has been calculated and placed in the last column. It will be noticed that the maximum mean annual forest per cent., 4·1, is realised under a rotation of 60 years, which is, therefore, the financial rotation. Under it the average girth of the trees comprising the final crop amounts to 50 inches. The proprietor desires, however, to secure a mean girth of not less than 60 inches, for which a rotation of 80 years is required. In adopting that rotation the proprietor reduces the mean annual forest per cent. by 4·1 − 3·9 = ·2 per cent.

The normal annual coupe amounts to $\frac{4,000}{80} = 50$ acres, that for the first period of 10 years to $50 \times 10 = 500$ acres. On a detailed examination of all compartments, it was found that, for silvicultural and protective reasons, the following areas require to be dealt with during the first 10 years :—

(1.) Silvicultural and protective necessities . .	90 acres.
(2.) Woods ripe and over-ripe	400 ,,
(3.) Woods of doubtful ripeness or woods which may become ripe during the first period .	50 ,,
Total	540 acres.

This is 40 acres more than the normal area ; hence, the area given under (3.) above may be kept back for treatment during the second period of 10 years. As there is, however, a surplus of 100 acres of woods over 40 years old, the area of 540 acres may stand to be dealt with during the first 10 years.

The yield during the next 10 years consists of the following items :—

(1.) The volume standing on the 540 acres to be finally cut and regenerated.

(2.) Five years increment on these 540 acres.

(3.) The estimated receipts from thinnings in the remaining areas during the 10 years.

The total number of cubic feet obtained from these three items, divided by 10, gives the average annual yield. These data are obtained by actual measurements in the forest. To explain the process in this place, the above yield table is used. Assuming that each wood at time of cutting is 80 years old, the final cuttings during 10 years would amount to $9,900 \times 540 = 5,346,000$ cubic feet. The sum of 9,900 cubic feet includes the thinnings between the years 70 and 80 (as well as 10 years increment) which would ordinarily be made. The area to be thinned in 10 years may be estimated as that stocked with timber between the ages of 20 and 70 years old, namely :—

Area in the age class 21—40 =	700 acres.
,, ,, ,, 41—60 =	800 ,,
,, ,, ,, over 60 =	760 (being 1,300 − 540).

Total area to be thinned in 10 years = 2,260 acres.

Assuming that one-fifth of this area, or 452 acres, is thinned at each of the ages of 30, 40, 50, 60 and 70, the total yield of thinnings would be estimated as follows :—

10 Thinnings at the age of 30 years	$= 410 \times 452 =$	185,320 cubic feet.
,, ,, ,, 40 ,,	$= 925 \times 452 =$	418,100 ,,
,, ,, ,, 50 ,,	$= 960 \times 452 =$	433,920 ,,
,, ,, ,, 60 ,,	$= 860 \times 452 =$	388,720 ,,
,, ,, ,, 70 ,,	$= 665 \times 452 =$	300,580 ,,
Total of estimated thinnings . .		1,726,640 cubic feet.

Repetition :—

Final cuttings.	Total = 5,346,000	Annual average .	534,600
Thinnings .	„ = 1,726,640	„ „ .	172,664
	Grand Total = 7,072,640	Annual average	= 707,264

This is equivalent to an average annual return of 177 cubic feet, representing an efficiency of 100 per cent. With an efficiency of 80 per cent., which can easily be obtained in spruce woods of I. quality, the return would be reduced to 142 cubic feet, and with one of 70 to ~~122~~ cubic feet per acre and year.
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h. Notes.

Under the uniform or compartment system, as described above, the regulation of the yield is effected by area, with due consideration for the proportion between the several age classes. The method is extremely simple, and leads to the establishment of the normal state of the forest. Other methods of regulation are, however, not excluded, as long as they lead to a sustained yield. A method frequently employed is to compare the yield calculated by area with the increment, and, if the two differ, to take the mean of the two and adjust the area to be regenerated accordingly. In other cases, the Austrian method is used for the calculation of the yield, and a corresponding area selected for regeneration.

The calculation of the yield for the uniform, or compartment, method with natural regeneration is practically the same as that for clear cutting, provided that the regeneration is completed during the working plan period. As a rule, this is not the case, and a part of the shelterwood has to be carried over into the next period ; on the other hand, a corresponding quantity has been taken over from the previous period ; it may be assumed that the one makes up for the other. It may occur that the regeneration period extends over two, three, and even more periods of 10 years. In all such cases the yield during the first period of, say, 10 years is calculated as follows :—

(1.) Yield calculated as in the above example, 7,072,640 cubic feet.

(2.) Plus amount of shelterwood taken over from previous periods, say 150,000 cubic feet.

(3.) Minus amount of shelterwood likely to remain at end of the period, and to be carried over into second period, 200,000 cubic feet.

(4.) Yield during first period = ~~7,072,640 cu~~bic feet.

7 022 640

The total amount, divided by 10, gives the average annual yield during the period 707,264 cubic feet. For an example of such a calculation see Appendix V. page 368

10. Modifications of the Compartment System.

In the course of time a considerable number of modifications of the compartment system have been elaborated. Some of these try to obviate certain disadvantages of the uniform system, others to meet special local conditions, and others are the outcome of personal fancies. The more important modifications will here be shortly described. They are :—

(*a.*) The French System known as the *Quartier Bleu.*
(*b.*) The Group System.
(*c.*) The Strip System.
(*d.*) The Strip and Group System.
(*e.*) Wagner's *Blendersaumschlag.*
(*f.*) The Wedge System.

With the exception of the first, the determination of the yield is effected in the same way as in the case of the compartment system.

a. The French Quartier Bleu System.

This modification of the shelterwood compartment system is based on the same principle as has been explained above, but differs somewhat in the manner of selecting the areas to be placed under ~~natural~~ regeneration. Instead of placing every 10 years a proportionate area under regeneration, under the *quartier bleu* system the average duration of regenerating a compartment is estimated. In dividing the rotation by that figure, the proportion of the area to be placed under regeneration is obtained, and that portion is kept up throughout the rotation. Taking the latter at 100 years, and the average duration of regeneration at 20 years, the regeneration area would be $= \frac{100}{20} =$ the fifth part of the area. If, for instance, the forest has an area of 1,000 acres, the regeneration area would amount to $= 200$ acres. That area is selected and painted blue on the forest map (hence the name), while the rest of the area remains uncoloured. From time to time—say, every 10 years—the 200 acres are

examined, any parts on which regeneration is complete are taken out of the blue quarter, and a corresponding area from the uncoloured part added to it. It is essential that regeneration should proceed at such a rate that it passes over the whole area of the forest in the course of one rotation.

The determination and regulation of the yield is done in some cases by area with a volume check, in others according to the French Ordinance of 1883. The latter was really designed for selection forests ; its principle is as follows :—

The exploitable girth, say 60 inches (representing the rotation), is divided into three equal parts or classes : Class I. = 1—20 inches, Class II. = 21—40 inches, Class III. = 41—60 inches. If the volume of the three classes were in the proportion of 1 : 3 : 5, the forest would be considered to be in a normal condition, and the volume in Class III. would represent the normal yield during the next 20 years. To test the matter, the trees of the II. and III. classes are enumerated and the volume in each of the two classes calculated. If their contents are found to be in the proportion of 3 : 5, the forest is assumed to be normal. If the proportion differs from 3 : 5, a sufficient number of trees is transferred from one to the other until that proportion is established. If the stock of the II. and III. classes are found to be above normal, the excess must be removed and the probable deficiency in the first-class trees made good, until the proportion between the three classes becomes as 1 : 3 : 5. It appears that in most of these cases the yield has been much underestimated in the past, probably the result of the somewhat uncertain method of calculation.

The following five systems owe their origin to the endeavour to obviate certain shortcomings of the uniform system of regeneration if applied to a considerable area, say a whole compartment, at one and the same time. If in such cases seed years come at the time when they are wanted, all goes well ; but if there is much delay in their arrival, or if (for other reasons) the regeneration should not be successful, the forester has left on his hands an opened-out area deteriorating under the effects of sun and air currents. Such areas have frequently to be restocked artificially. To avoid this disadvantage, or at any rate to minimise it, it is desirable to reduce the area taken in hand in the first place to a number of small groups or a narrow strip, or the two combined.

b. The Group System.

With a view to reducing the area opened out in a wood under regeneration to a minimum, only small or moderate-sized groups are taken in hand, and when these have been regenerated others are taken up, and so on until the whole compartment, or wood, has been regenerated. An alternative method is to remove the old wood over any groups of advance growth and enlarge them from

Fig. 59.—Showing a group with its height decreasing from right to left, joining a second group on the left.

time to time until the several groups join. In most cases both methods are combined.

The regeneration period under this system is generally much longer than under the uniform system, extending frequently to 30, 40, and even more years. Consequently, the regeneration area must be correspondingly increased (see page 306 of this volume).

c. The Strip System.

Instead of groups scattered over the compartment, a strip is taken in hand at starting. Its breadth should not be more than

twice the height of the wood and frequently not more than once; it may, however, be of any length. The first strip should be situated at that end of the compartment where it is best sheltered either against wind or the sun, or both if possible, according to local conditions.

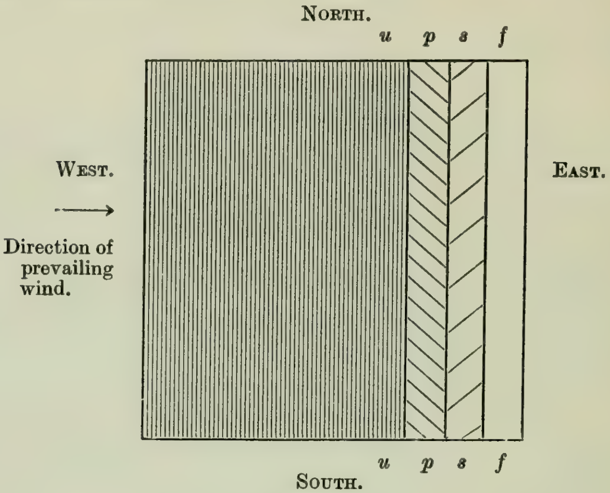


Fig. 60.

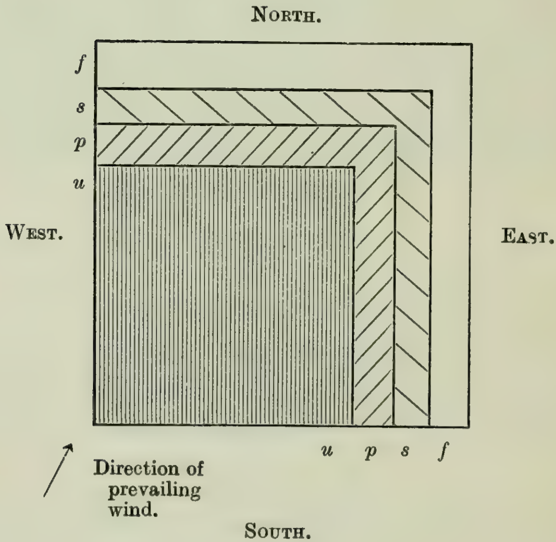


Fig. 61.

In the first year a preparatory cutting (if necessary) is made. A few years afterwards a seeding cutting is made, and a preparatory cutting in a second adjoining strip. In the following years the first strip is in the final stage, the second in the seeding stage, and a preparatory cutting is made in a third strip. There are always three strips under regeneration, and in this manner the regeneration proceeds until it reaches the other end of the compartment.

d. The Strip and Group System.

Under this combined system a strip is taken in hand to begin with, but, instead of dealing with it in a uniform manner, only groups are opened out in it as described for the group system. While these are being enlarged, a series of further groups are com-

Fig. 62.—Group and strip systems combined. Regeneration commenced on the right and proceeded towards the left. The strip on the extreme right has been cleared of shelter trees.

menced in a second strip; in other words, the groups march somewhat ahead of the final clearing of the previous strip. This procedure continues until the further end of the compartment has been reached.

e. Wagner's Blendersaumschlag.

Blendersaumschlag may be rendered in English as "Selection Border Coupe." The method attempts regeneration by a series of narrow strips, each of which is situated at the border of the old wood. In this way regeneration begins at one end of the wood and moves gradually through it until the further end is reached.

In this respect the system does not differ from the ordinary strip system described above. There are, however, differences in the nature of the cuttings. Instead of having three distinct stages —the preparatory, seeding, and final—Wagner employs a series of selection fellings which produce a new crop of somewhat uneven

age in each group. As the system aims at a very high degree of efficiency, it is desirable to give some further details.

Wagner, as a decided advocate of natural regeneration under a shelterwood, was much impressed by the shortcomings of the natural regeneration under the uniform compartment system, especially as regards the effect of the sun and climatic factors upon the soil and the young growth, as well as the damage done to the young crop by the removal of the shelter trees. With a view to establishing an improved strip system, he started a long series of experiments and observations, so as to define the extent to which the above-mentioned agencies affected the progress of regeneration, and to devise measures for reducing their damage to a minimum.

In his inquiry, Wagner paid special attention to the following points :—

(1.) The direct effect of the sun on the desiccation of the soil and on the destruction of seedlings.

(2.) The desiccating effect of dry east and north-east winds.

(3.) The accessibility of light rain (especially from the west) to the regeneration area.

(4.) The formation of dew and the length of its retention on the ground.

(5.) The exposure of the regeneration area to strong winds.

(6.) The removal of the shelter trees without injuring the young growth which has sprung up under their shelter.

On the basis of the information thus obtained, Wagner arrived at the following conclusions as regards the effect of exposure from the various points of the compass :—

(*a.*) *East* and *south-east* are altogether unfavourable ; the sun penetrates into the inner part of the strip ; light rains from the west do not reach it ; dew is at once dried up by the morning sun ; there is much danger from frost ; desiccating winds from the east are very injurious.

(*b.*) *South* and *south-west* are nearly as unfavourable, but dry east winds do less harm ; south-west sides benefit by light west rains, but receive the full effect of the afternoon sun and suffer from strong west winds.

(*c.*) *West* is somewhat more favourable ; the midday sun is kept out of it, but it suffers from the afternoon sun and

from western strong winds and gales ; light rains enter it freely.

(*d.*) *North-west* sides are very favourable ; they give access to light western rains, and are protected against the midday sun and dry east winds, but only partially against western gales ; dew is freely formed and retained.

(*e.*) *North* sides are very favourable ; they are protected against the sun ; dew forms freely and is retained for a long time ; they rarely suffer from strong winds and only moderately from dry east winds ; light westerly rains, however, reach only the outer part of the strip.

(*f.*) *North-east* sides are sheltered against the sun during the whole day, except in the early morning ; during the latter time dew is liable to be dried up ; they do not receive light rains from the west, and are exposed to north-east winds.

To sum up, Wagner considers, on level and gently sloping ground, aspects between north-west and north-east as favourable for regeneration, those between east and south-west as unfavourable, while west holds an intermediate position. He proposes that the regeneration of each individual strip should proceed from north to south, and that the progress of the whole operation should proceed from east to west, or from north-east to south-west, as indicated in Figs. 63 and 64. In hilly country the cutting direction depends to a great extent on the local wind direction.

To make sure that the border of the old wood, where regeneration is expected, points to the north, Wagner gives the edge of the old wood a broken-up shape. If the forward movement is from the north-east to the south-west, the edge presents the shape of a series of steps ; if the movement is from east to west, the edge consists of a series of triangular openings or bays, as shown in the appended illustrations, Figs. 63 and 64. While regeneration in the first strip is proceeding, the first selection felling in the second strip works somewhat ahead of the strip actually under regeneration, and so on.

The number of fellings in each strip is not fixed ; it depends on the progress of regeneration. The removal of the felled trees is effected through the old wood, all trees being thrown in that direction, as shown in the illustrations. In this way, practically

no damage is done to the young generation.* It remains to add that the determination and regulation of the yield is based on area, as in the ordinary uniform compartment system.

Wagner's main object is to reduce the desiccating effect of the

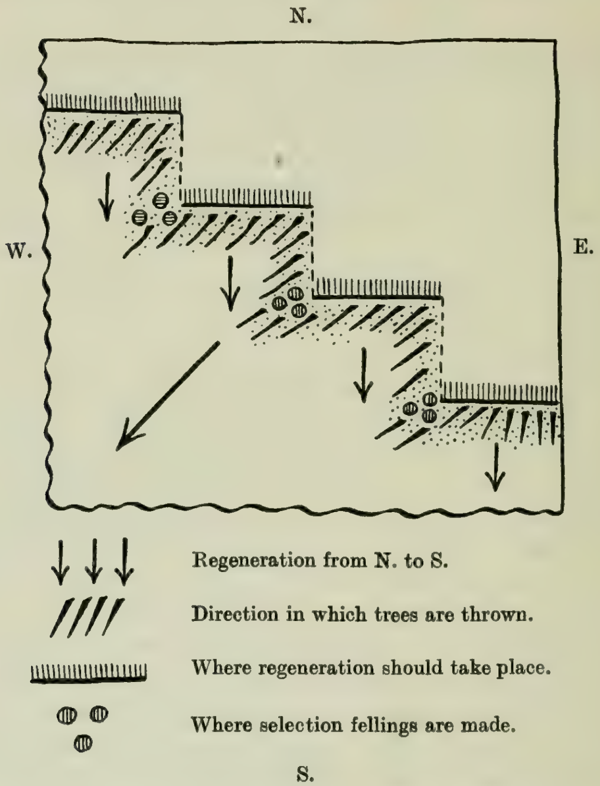


Fig. 63.—Wagner's *Blendersaumschlag* Cuttings in the shape of Steps. (After Wagner.)

sun on young regeneration to a minimum and to secure as favourable a degree of moisture in the soil as possible, especially during the growing season. The importance of this has, of late years, been more fully recognised in consequence of unfavourable

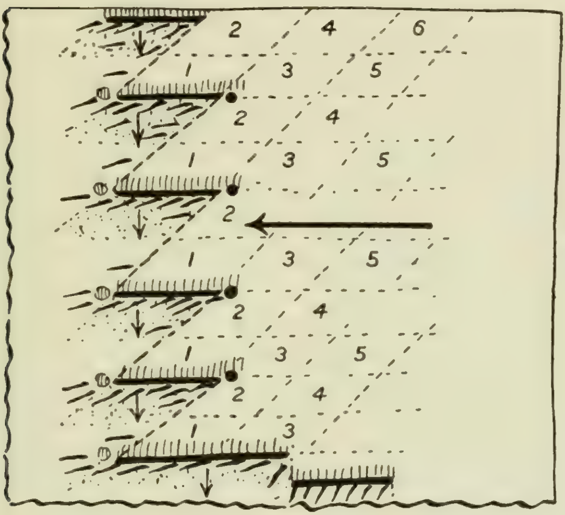
* Readers who desire further information on the method will find it in Wagner's two works: "Die Grundlagen der raeumlichen Ordnung im Walde" and "Der Blendersaumschlag und sein System," both published by H. Haupp, Tuebingen.

results in attempted regenerations. It has been recognised by foresters that, in order to obtain the best possible results, the soil must be kept under continuous protection in all cases where the rainfall is not favourably distributed over the year ; in other words, that regeneration under a shelterwood, whether natural or artificial, gives, in the long run, better results than clear cutting with subsequent planting or sowing. In Saxony, for

PROGRESS OF REGENERATION FROM E. TO W.

N.

W.



E.

S.

Fig. 64.—Wagner's *Blendersaumschlag* Cuttings in the Shape of Bays. (After Wagner.)

instance, detailed investigations carried out during the last three years have shown that the woods raised during the last 100 years by clear cutting and planting have produced considerably smaller volumes per acre than those reared formerly under shelterwoods.

f. The System of Wedge Fellings.

This method, elaborated by Dr. Eberhard at Langenbrand in the Black Forest, is a modification of the strip system, in which the chief objects are :—

(*a*.) To expose the longest possible front to regeneration.

(*b*.) To prevent damage by wind.

(*c.*) To avoid damage during the felling and extraction of the produce.

Dr. Eberhard produces these effects in the following manner :—

On level or gently sloping ground, in each compartment a number of long narrow wedges are felled against the prevailing wind direction. These wedges are from 10 to 15 feet wide, and of any length, but leaving a protection belt at each end of the

DR. EBERHARD'S SYSTEM OF WEDGE FELLINGS.

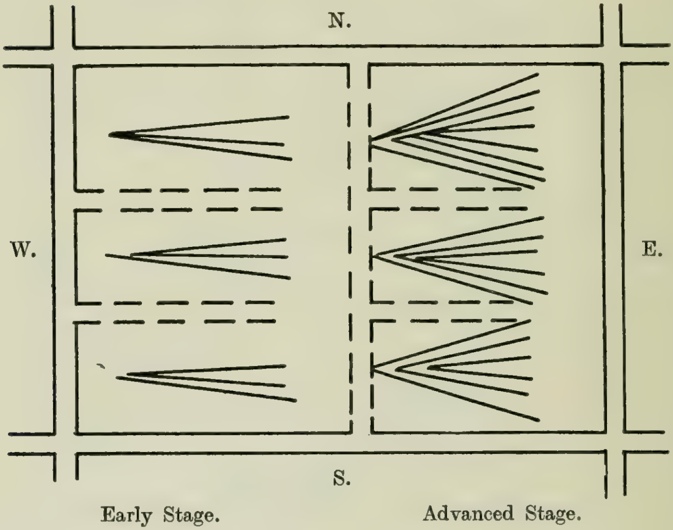


Fig. 65.—Wedge Fellings. (After Troup.)

wedges. Subsequently these wedges are widened by narrow cuttings on each side as soon as regeneration has appeared on the first opening, and this process is repeated from time to time until the borders of the compartment are reached ; at the same time the apexes of the wedges are advanced towards the wind direction until they reach the further edge of the regeneration area. In this way, the several wedges join up and, after the protection belts have been treated in a similar way, the whole area becomes regenerated (see Fig. 65).

The produce is removed through the unregenerated parts to the nearest road. It is assumed that if wind enters the wedges it

escapes as through a funnel towards the east; also that the wedge-form disperses and reduces the force of the wind. On steep slopes the wedges run down-hill, to facilitate the sliding of the logs to the lower edge of the strip. In this case, the openings are made broader on the east than on the west side.

It is said that regeneration is very complete under this system, but the method is of a very complicated character, requiring the constant attention of the forester. The yield is regulated by area.

11. The Coppice System.

Character of the System.—When a wood, chiefly consisting of broad-leaved species, has been cut over near to the ground, the stool or roots, or both, produce shoots which develop into a new crop called simple or ordinary coppice. Generally, several shoots spring from the same stool, and these stand in clumps forming a complete cover earlier than in the case of seedling woods. When this has been established, the wood presents the appearance of a thicket in high forest. It grows up into poles and, under favourable conditions, into trees. This method of regeneration can, as a rule, be repeated as long as the stool and roots live.

Coppice woods suffer more than seedling crops from late and early frost, because the shoots are more succulent, and they require during the first year a longer growing season to ripen before autumn frosts set in. On the other hand, damage by frost is more easily healed. Coppice also suffers much from damage by game, especially deer and rabbits; mice also do much damage. In other respects, coppice is less affected than high forest.

Coppice woods yield chiefly firewood and small timber. Oak coppice gives bark for tanning, which has, however, been much superseded by other materials. The number of cubic feet of wood produced per acre and year is generally much smaller than in the case of high forest.

Owing to the rapid growth of the shoots during the first few years, a complete cover overhead is quickly established which protects the soil well; on the other hand, the latter is more frequently laid bare than in the case of high forest.

Determination of the Yield.—In the first place, the rotation must be fixed in accordance with the class of produce which it is desired

to grow. By dividing the total area (real or reduced) by the number of years in the rotation, the size of the annual coupe is obtained. In the case of extensive areas, or for the purpose of supplying markets in different directions, it is frequently desirable to divide the forest into two or more working sections, allotting to each a number of coupes equal to the number of years in the rotation. In some cases, different rotations for the several working sections are indicated. A separate account should be kept for each working section. The coupes should be marked on the ground.

The final yield is ascertained by estimating the returns which may be expected from the areas to be cut over during the working plan period and dividing them by the number of years in the period. Intermediate returns consist of the cuttings made in all areas not put down for regeneration during the working plan period ; they are, as a rule, not of much importance. Their amount should be estimated according to average local figures obtained in the past.

12. The Coppice with Standards, or Combination, System.

(See pages 202—207.)

Character of the System.—The system is a combination of simple coppice with standards of uneven age treated under the high forest selection system. The coppice forms the underwood, and the standards the overwood, the two being treated under different rotations. Generally, cuttings are made in both underwood and overwood in the same year ; that is to say, when the underwood has arrived at the end of its rotation, it is cut over, and at the same time those standards are removed which have reached the end of the rotation fixed for the overwood, or which it is desirable to remove for other reasons. New standards are then introduced, which, as a rule, should be seedlings and not coppice shoots. The rotation of the overwood should be a multiple of that fixed for the underwood. The number of that multiple depends on the size of timber which it is desired to produce. As a matter of fact, the latter consideration is, in the majority of cases, the deciding factor.

The actual proportion of standards in each age gradation depends on the objects of management. The numbers form a falling

series from the youngest to the oldest gradation. The total number of standards must not be so great that the coppice is deprived of the necessary light; hence, it is smaller than the number of trees in a regulated selection forest. Generally, the standards are scattered over the area by single trees, but in some cases they are in small groups.

As regards external dangers, the system partakes of the advantages and disadvantages of the simple coppice and selection systems, according as it approaches the one or the other. If properly treated, the system acts beneficially upon the factors of the locality, though not to the same extent as the regulated selection forest. The production of wood is smaller than that of high forest. On the other hand, it permits the production of exceptional dimensions of trees without endangering the activity of the producing factors of the locality.

Determination of the Yield.—The first step is to effect a division into compartments or annual coupes, and to allot them to as many working sections as may be required. There should be as many coupes in each working section as there are years in the rotation of the underwood. This regulates the yield as far as the underwood is concerned. The determination and regulation of the yield of the overwood is effected on the same lines as those explained for the regulated selection forest. Each compartment, or coupe, is treated on its own merits. In selecting the standards for cutting, the forester is guided, subject to the objects aimed at by the proprietor, by silvicultural considerations and the degree of ripeness of the several trees. Whenever a sustained yield is aimed at, not more should be cut during the working plan period than the increment laid on during the same period, but allowing for a deficiency or surplus of growing stock. At starting, the forester should make the best possible estimate of the increment during the first period of r years, remeasure the stock of standards at the end of the first period and thus obtain a more accurate estimate of the expected increment during the second rotation of r years (see Selection Forest above). By adding the yields of the underwood and of the standards, the total yield is obtained. To that amount should be added the produce obtained by any thinnings made in other compartments, the amount of which should be estimated on the basis of local experience.

SECTION II.—AUXILIARY SYSTEMS.

A variety of auxiliary systems are practised. They are generally dealt with in Silviculture, and, as regards the regulation and determination of the yield, they do not differ from the principal systems upon which they are grafted. Hence, a few remarks on some of the more important suffice in this place.

1. High Forest with Standards.

During the regeneration of a high forest, single trees or small groups of trees are left standing, with the object of producing trees of a larger size than can be obtained in one generation. The length of time during which these standards are retained differs, according to the required size, from a limited number of years to a full second regeneration, and in some cases even more. In former times, masts of ships used to be produced in Europe by this system. From an economic point of view, the system has considerable drawbacks. In the first place, it is financially unremunerative. Secondly, the standards interfere considerably with the development of the new crop, unless they consist of a thin-crowned, light-demanding species; and if they are removed before the end of the second rotation, they are liable to do much damage to the second crop. Standards of broad-leaved species are liable to develop epicormic branches, which may reduce the quality of the timber; they must be removed by pruning. Unless the standards are very wind-firm, they are liable to be thrown prematurely.

2. The Two-storied High Forest.

In a wood consisting of one or more light-demanding species, a time arrives, at a comparatively early age, when the leaf canopy becomes interrupted, so that it can no longer preserve the factors of the locality. In such a case, a fairly heavy thinning is made, removing all inferior or otherwise undesirable trees, and a second crop, consisting of a shade-bearing species, is introduced, generally by sowing or planting. The two crops are then allowed to grow up into high forest with a difference in age ranging from 15 to 60 years, according to species and local conditions.

Of interesting examples of this kind the following are mentioned :—

(*a.*) At Novar, Scotland, 15 to 20 years old larch have been underplanted with silver fir, spruce, Douglas fir, and various other shade-bearing species (see Fig. 66).

(*b.*) In the Spessart, Weiserstein, and elsewhere, oak at the age of 50 to 60 years is underplanted with beech (see Fig. 67).

(*c.*) In the forests of the Vosges, France, Scots pine, about 60 years old, has been undersown with silver fir.

In some cases the two species are cut over at the same time, followed by a fresh start on the same lines. In other cases, the older wood is removed when the trees have reached the desired dimensions, and the younger wood is allowed to grow to maturity. In the Spessart, where the object is to produce specially large oaks, the beech is cut over when mature, and a second crop of beech is grown and cut with the oak.

In these cases the determination and regulation of the yield is done on the lines described for the uniform system, but for each story separately.

3. High Forest with a Soil-protecting Wood.

When the leaf canopy of a high forest begins to become interrupted, an underwood is introduced for the protection of the soil. This must be dense and not too old ; hence, it should be replanted from time to time, or, better still, coppiced periodically ; it must consist of a species which can stand the shade of the overwood, the latter consisting of a thin-crowned species. The effect on the factors of the locality is highly beneficial. The system has been largely used in the oakwoods of Britain.

4. Forestry combined with the Growing of Field Crops.

The practice of growing field crops on forest land is very old. There is evidence to show that it was extensively practised in Ceylon more than 1,000 years ago, and probably much earlier—in fact, ever since the human race commenced cultivating the soil. The original method consisted in cutting down the crop on a piece of forest, allowing the wood to dry and then burning it. After the ashes had been scattered over the area, rice, other grains and vegetables were grown for one or two seasons, after which

the soil was allowed to recover itself with forest growth. The system is still practised in most parts of the British Empire. In India it is known under a variety of names, such as *jhooming, dhya, kumri, taungya* cultivation, etc. In European countries, in the course of time, some order was brought into the system; the timber, instead of being burnt, is utilized, only the twigs and other inferior pieces being burnt. The system is practised in two distinct forms, in connection with coppice woods or with high forest.

Fig. 66.—Larch, 25 years old, as Overwood, and *Tsuga hederophylla,* aged 8 years, as Underwood.

In the case of coppice woods, after the twigs and other pieces of wood, frequently mixed with turf, have been burnt, the soil is generally used for the cultivation of buckwheat and rye between the stools of the previous crop. In some cases, the two seeds are sown together, say, in June, the buckwheat is harvested in August and the rye in the following summer. In other cases, they are cultivated one after the other.

The cultivation of field crops in connection with high forest has been practised in Europe for a long time past. In France it is known by the name of "sartage," and much practised in the

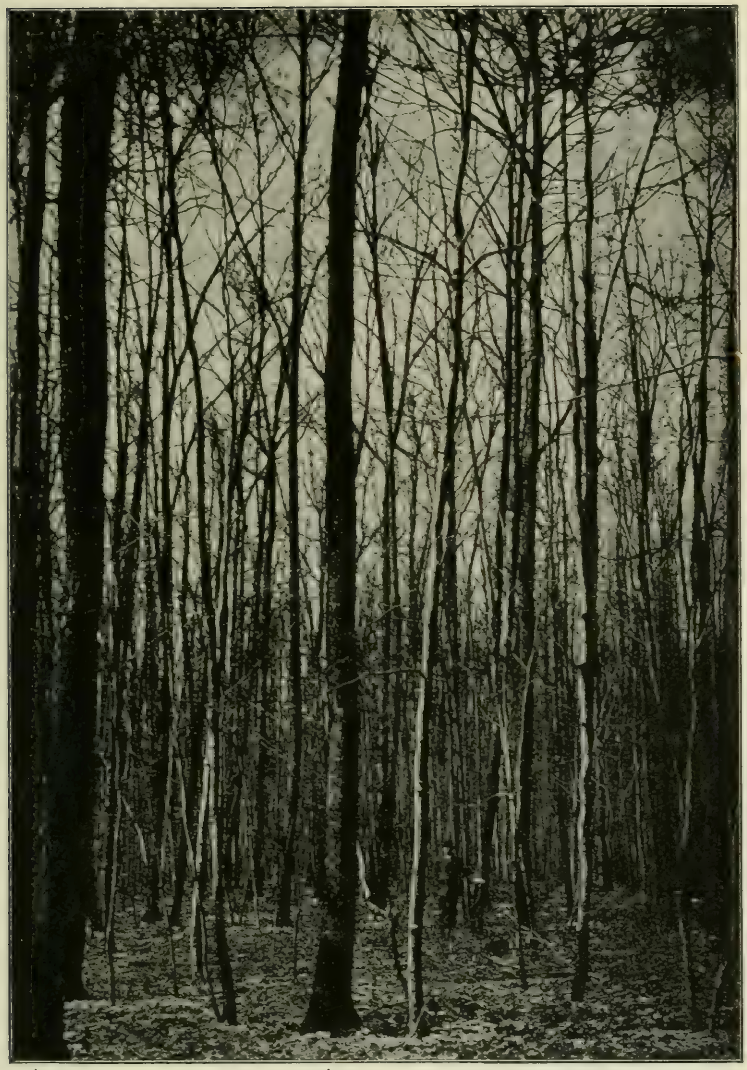


Fig. 67.—Oak Wood, 110 Years Old, with Beech Underwood, 53 Years Old (Weiserstein; Spessart).

Number of oaks per acre = 240.

Total production of oak timber, quarter girth measurement = 5,670 feet.

Production per acre and year = 52 cubic feet, valued at £4, apart from the beech.

Soil a sandy loam of only middling quality, overlying old red sandstone. Oaks clear of branches for 50 feet.

regeneration of coniferous woods. In Germany, large areas have been restocked under this system with Scots pine, oak, and other species during the last 120 years. After the old wood (timber, firewood and stools) has been removed, the soil is worked, planting or sowing of seed is done in lines, and between the lines cereals, potatoes and other crops are grown for two, three, and even four years.

In Burma, the system has been used in the cultivation of teak since the year 1866. The author saw one of the earliest attempts in 1867 in one of the forests near Toungoo. Since then many thousands of acres have been stocked with flourishing teak woods. During the last few years, the system has been adopted in the regeneration of sāl and other species in India proper.

5. Forestry combined with Pasture.

Pasture lands are widely planted with forest trees, which yield a certain return and also improve the value of the pasture by moderating cold and dry winds, thus affording shelter to the cattle. Broad-leaved species may also be lopped for fodder in cases of necessity. Strong seedling plants are used for the establishment of the woods, which should be protected until their crowns have grown beyond the reach of the cattle.

6. Forestry combined with the Rearing of Game.

A forest which is fenced and stocked with deer or other game is called a "deer forest" or "game preserve." All inside areas which are under regeneration must be separately fenced. Species which produce food for the deer, especially oak or chestnuts, should be represented in deer forests. Scottish deer forests are, as a rule, not fenced. They consist chiefly of extensive open areas ; at the same time it is desirable that the deer should have access to some forest areas, as it improves their development, especially the size of their antlers.

Pheasant preserves are found in all parts of Britain. Any form of forest can be used for the purpose, but the most suitable system is coppice with standards. The underwood should consist of fairly shade-bearing species, such as beech, hornbeam and hazel, but ash is also extensively used, as it is more profitable and stands a moderate amount of shade while young ; even birch is used in

fairly open parts. The overwood should consist of fairly thin-crowned species, such as ash, oak, larch, poplars and perhaps some pines.

Fenced rabbit warrens also occur in woodlands, but they, naturally, end in the destruction of the forest.

SECTION III.—THE CHOICE OF SYSTEM.

The choice of system depends on a variety of considerations, the details of which are dealt with in Silviculture. In this place it will suffice to draw attention to some of the most important aspects. These are :—

(1.) The objects of the proprietor, whether he aims at indirect effects, or the production of the greatest volume, the highest quality, a special class or size of produce, or a high financial return, etc.

(2.) The local conditions, such as the nature of soil and climate, the configuration aspect and gradient of the locality.

(3.) The species best suited to realise the objects of the proprietor and also suitable to the local soil and climate.

(4.) The dangers which may threaten a particular class of forest growth, such as frost, drought, insects, fire, wind, weeds and disease.

The preservation and, if possible, improvement of the fertility of the soil is the most important consideration ; hence, the choice between regeneration on clear-cut land and under a shelterwood must be carefully considered. The former is, generally speaking, admissible only on land which is not only fertile, but also subject to a sufficient rainfall favourably distributed over the several seasons of the year. In all other cases, the exposure of the soil to the full effect of the sun and air currents extending over a number of years leads invariably to a reduction of its fertility. To prevent this, a system must be chosen which provides for a regeneration under a shelterwood. Then arises the question : which of the latter class systems is preferable ? There cannot be any doubt that of these the regulated selection system gives the best protection, and next to it the uniform system or one of its modifications. Of the latter, Wagner's modification may be specially recommended.

The Austrian, Hundeshagen's and von Mantel's systems deter-

mine the yield by a formula and give full liberty in other respects, so that they can be applied to the clear-cutting or shelterwood systems. They can also be used as a check on the determination of the yield by area. Heyer's method combines the determination of the yield by volume with one by area, which makes it somewhat complicated.

The system of the division of the area into fixed annual coupes is applicable only to coppice and coppice with standards ; it is too stiff for other purposes.

The comparative volume production and the value of the returns is of great importance in the selection of the system. They can be decided only by statistical data derived from the results of experiments, which are generally brought together in volume- and money-yield tables. Much has been learned in that way, but not all that is required to arrive at final conclusions in many respects. So far it may be said that the uniform system and its modifications give the highest volume production, but that of the regulated selection forest should not be much below it, if at all. The value per unit of volume produced in even-aged woods under the uniform system is generally somewhat higher than in the case of selection forest. On the other hand, the general expenses of the former system are likely to be higher than those of the latter ; hence, it is questionable which of the two systems is the more profitable—in other words, which of the two gives the higher mean annual forest per cent.

The qualifications of the managing forester are of importance in the selection of the system. Where a thoroughly qualified staff is available, as in India, in Great Britain and in some parts of the Colonies, any system can be adopted which may be advisable under the existing local conditions. Where such a staff is not yet available, a simple system may give better results than attempting a more complicated method.

Generally speaking, the choice of the system depends on the degree of intensity of management which has been reached. In the greater part of the British Empire the selection system is as yet indicated. As the staff and the intensity of management improve, the regulated selection system will probably be the next stage, to be followed in many cases by the uniform system or some of its modifications.

SECTION IV.—CONVERSION FROM ONE SILVICULTURAL SYSTEM TO ANOTHER.

As a general rule, the returns during the period of conversion are likely to be uneven in amount. If the new system requires a higher rotation than that to be abolished, the returns will be smaller, until the conversion has been completed, and possibly even longer. Hence, before a change of system is undertaken, it should be carefully considered, whether the advantages expected from the change are likely at least to compensate for the unavoidable disadvantages.

The number of conversions from one silvicultural system to another which are conceivable is considerable, and it is impossible to give any general rules of procedure. Whatever the nature of the conversion may be, the only sure basis for the determination of the expected yield is the annual cutting area. Hence, the consideration of a few special cases will bring out the essential points to be considered in each conversion.

1. Conversion of the High Forest Selection System into the Uniform, or Compartment, System.

This conversion necessitates the substitution of even-aged for uneven-aged woods, and it frequently involves the cutting over of trees at an age differing from that which is most advantageous. To justify this sacrifice, the compartment system must offer decided advantages over the selection system.

It is usual to fix one rotation for the conversion, to divide the rotation into periods of even lengths, and to allot to each period a corresponding portion of the total area, with due consideration of the condition of the several woods. As a rule, the several age classes are not evenly distributed over a selection forest; generally, more old wood is found in some parts of the area, and more young wood in others. This fact is taken advantage of in the allotment—that is to say, Period I. receives those woods which contain most old trees, especially those with deficient increment, Period II. receives the woods which are richest in middle-aged trees, and so on. In effecting this allotment, a proper grouping of the future age classes and cutting series must not be overlooked

Example.—Assuming the rotation to be 120 years and the whole area allotted to three periods of 40 years each, the working during the first rotation would be as follows :—

During Period I.—Part A, approximately equal to one-third of the total area, will be regenerated, either naturally or artificially, or by a combined method. From part B any over-mature trees are removed by selection, the necessary thinnings made, and blanks, if any, stocked. In part C over-mature trees are removed, blanks stocked, incomplete young woods filled up, and others thinned.

During Period II.—Part B will be regenerated. In part A any remaining shelter trees will be removed and probably thinnings commenced. In part C over-mature trees will be cut and thinnings made wherever necessary.

During Period III.—Part C will be regenerated. In part B any remaining shelter trees will be cut and thinnings commenced. In Part A the necessary thinnings will be made.

The following table will further illustrate the procedure :—

Period.	Part A.	Part B.	Part C.
I. 1—40 years.	*Regenerated.*	Over-mature trees removed. Thinnings made. Blanks stocked.	Over-mature trees removed. Thinnings made. Blanks stocked. Incomplete woods filled up.
II. 41—80 years.	Any shelter trees removed. Probably thinnings commenced.	*Regenerated.*	Over-mature trees removed. Thinnings made.
III. 81—120 years.	Thinnings made.	Any shelter trees removed. Probably thinnings commenced.	*Regenerated.*

2. Conversion of Coppice into High Forest.

This conversion may be effected by one of two methods : (*a*) Thin the coppice once or twice, leave the most vigorous, well-shaped shoots, let them grow until they have reached a marketable size and are capable of producing good seed ; then regenerate. As coppice shoots do not produce, as a rule, the same class of trees as those grown from seed, the regeneration of the former should be effected at a comparatively early age—say, when the annual increment has reached its maximum. The method has the disadvantage that no final yield is obtained for a considerable num-

ber of years ; even the thinnings may be of comparatively small value. (*b*) Cut the coppice when it has reached the usual age, and interplant the stools with seedling plants, preferably of a species of rapid growth. The fresh stool shoots will have to be cut back once or twice, until the seedling trees have reached a sufficient height to hold their own against the coppice shoots, which will then become an underwood or gradually die.

In all cases where, in the future, a sustained annual or periodic yield is desired, the area should be divided into a corresponding number of annual or periodic coupes of equal yield capacity. If the new wood consists of a coniferous species, it is necessary to arrange suitable cutting series.

The determination and regulation of the yield is done by area.

3. Conversion of Coppice with Standards into the Compartment System.

This conversion can be effected by gradually growing so much overwood in each coupe that it represents a full high forest. For this purpose, the coppice with standard system is continued for a time, but as little as possible overwood cut, and as many poles as possible left standing, until the area is fully stocked with overwood. The poles thus left should, if possible, be seedling trees and not stool shoots. Another method is to grow the high forest direct out of the underwood, provided the latter contains a sufficient number of seedling trees, and has not suffered by too much cover overhead. In either case, a good deal of planting or sowing may be necessary.

To prevent a great unevenness of returns during the first rotation, the conversion will be effected only gradually, as indicated under 1. Conversion of a Selection Forest.

Example.—If the future rotation of the high forest be 120 years, the work would be distributed as follows :—

During Period I., of, say, 40 *years.*—Convert one-third of the area ; cut very sparingly in the second part of the area ; cut as usual in the third part.

During Period II., of 40 *years.*—Convert the second part ; cut sparingly in the third part. Thinnings will be commenced in the first part.

During Period III., of 40 *years.*—Convert the third part. Thinnings in the first part will be in full swing. Thinnings will be commenced in the second part.

4. Conversion of a Forest of Broad-leaved Species into a Forest of Conifers.

An irregularly stocked forest of broad-leaved species, partly high forest, partly coppice, and partly coppice with standards, is to be converted into a coniferous forest, a conversion which is indicated by the special conditions of the locality.

The first and most important step is to divide the forest into a suitable number of compartments by laying out a system of roads and rides suitable to the locality. These compartments are then grouped into a suitable number of cutting series, without taking into consideration the present conditions of the several woods, but merely future requirements.

It would be problematic to determine the rotation to be adopted for the future coniferous forest. On the other hand, the age should be determined which the oldest coniferous wood should have reached when the conversion has been concluded, so as to have, from that moment forward, woods of sufficient age to cut and supply the market. This age determines the period during which the conversion is to be effected, called the "conversion period." The latter must not be too short, or else there would be no final cuttings for a number of years after the conversion had been completed. Supposing 60 years were chosen for the period of conversion, then at its close the oldest coniferous wood would have an age of 60 years.

By dividing the total area by 60, the area is ascertained which should be converted annually.

In selecting the areas to be taken in hand year by year, two considerations present themselves :—

(1.) A suitable arrangement of the future cutting series.

(2.) To begin with cutting over the woods which are poorest in increment.

A consideration of both decides the allocation of the annual coupes over the forest area.

Example.—A coppice with standard forest of 1,200 acres shall, in the course of 60 years, be converted into a coniferous forest. Every 10 years $\frac{1,200}{6} = 200$ acres must be taken in hand for conversion. In that case, the yield would consist of :—

During the first 10 years—
(1.) The clearing of 200 acres.
(2.) The treatment of 1,000 acres as coppice with standards.
During the second 10 years—
(1.) The clearing of 200 acres.
(2.) The treatment of 800 acres as coppice with standards.
During the third 10 years—
(1.) The clearing of 200 acres.
(2.) The treatment of 600 acres as coppice with standards.
(3.) Thinnings in the oldest coniferous woods.
And so on.

It is evident that the returns fall off from period to period, in so far as the reduction is not made good by thinnings in the young coniferous woods. This can to some extent be modified by not making any cuttings in the area of coppice with standards which will come under conversion during the next period of 10 years—in other words, by letting the material become 10 years older than it otherwise would. A similar arrangement should be followed during the third period of 10 years. After that time the thinnings in the young conifer woods should equalise the annual yield.

The expected yield is determined by estimating the returns from the area to be converted during the first period and adding thereto the necessary cuttings on the rest of the area ; the latter should be sparingly done, so as to equalise the cuttings as much as possible.

CHAPTER V.

CONTROL OF EXECUTION AND RENEWAL OF WORKING PLANS.

It is not sufficient to prepare a working plan ; it is also necessary to see that its provisions are carried out ; and when the period for which it lays down the management of a forest has come to an end, a new, or rather a revised, plan must be prepared.

As the preparation of a first working plan is to some extent based upon incomplete data, it is of importance to keep a careful record during its execution, so as to eliminate in the course of time all doubtful elements. Apart from this, changes in areas or in other respects may occur which must be noted. The work of control and renewal comprises, therefore, three distinct operations :—

(1.) The record of changes as they occur.

(2.) The record of works.

(3.) The preparation of revised working plans from time to time, or renewals.

TABLE OF YIELD, RECEIPTS,

Year.	Area, Acres.	Wood Sold, in Solid Cubic Feet.				Receipts, Shillings.			Expenses,	
		Timber.	Fire-wood.	Bark.	Total.	From Wood.	From Minor Produce.	Total.	Harvesting of Wood.	Harvesting Minor Produce.
1891	253	12,300	7,000	100	19,400	7,600	400	8,000	1,200	100
1892										
.										
.										
1900										
Total ..	..	130,000	70,000	1,000	201,000	75,000	4,000	79,000	14,000	900
Annual Average	253	13,000	7,000	100	20,100	7,500	400	7,900	1,400	90

1. Record of Changes.

(*a.*) All changes in the areas must be recorded. Part of the area may be sold or exchanged, or additional areas bought; areas hitherto used for the production of wood may be set aside for other purposes, or *vice versâ.* The progress of the cuttings may cause alterations in the allotment of areas; natural phenomena may produce changes, such as floods, landslips, fires, etc. All such changes should be noted at the close of each year, in the maps as well as in the tables of areas.

(*b.*) All final cuttings should be entered on the record and the maps.

2. Record of Works.

The record of works has for its object—

(*a.*) To give a general view of all cuttings in the forest and their distribution over the several woods or compartments.

(*b.*) To give the means of comparing the provisions of the working plan with the execution or actual results.

The special form to be adopted depends on local circumstances, but information on the following points is required:—

(1.) Result of each cutting according to quantity and amount realised by its sale.

and Expenses.

Shillings.					Net Result, in Shillings.		Forest Capital, Shillings.			Percentage given by Forest Capital during Year.	Remarks.
Formation and Improvement.	Administration and Protection.	Taxes, etc.	Miscellaneous.	Total.	Total.	Per Acre.	Soil.	Growing Stock.	Total.		
200	400	200	100	2,200	5,800	22·92	31,100	128,700	159,800	3·63	
2,100	4,000	2,000	1,000	24,000	55,000	..	..	..	..	..	
210	400	200	100	2,400	5,500	21·74	31,100	128,700	159,800	3·44	

(2.) A comparison of the estimate with the actual results.

(3.) The harvest of minor produce according to receipts and, if possible, quantity.

(4.) The data showing the net results of management. For a sample see the table on pages 338 and 339.

(5.) The means of following up the history of each wood or compartment, as illustrated in Appendix VI., page 378.

3. Renewal of Working Plans.

The renewal may in some cases amount to an entirely new plan; but in the majority of cases much of the work done on the first occasion can be used again, only subsequent changes being noted.

The most important part of what remains from the provisions of the first working plan is the allotment of areas, or the order of cuttings then initiated; but even this frequently requires modification.

The task at a renewal is, strictly speaking, the same as on the first occasion, except that a good portion of the work need not be done over again, and that the experience gained during the past period makes that task much easier than on the previous occasion. Hence, it may be indicated as follows:—

(*a.*) Investigation of the manner in which the provisions of the former working plan have been carried out, whether there were reasons for departing from them, and, if so, what they were.

(*b.*) Investigation of the extent to which the provisions of the former working plan were judicious and appropriate.

(*c.*) Proposed changes, especially as regards the silvicultural system, species, method of formation, tending, and any other important operation.

(*d.*) Preparation of a new working plan, based upon—

- (1.) The old working plan.
- (2.) The corrected records and maps.
- (3.) The results of past yields in material and money.
- (4.) The account of past works of formation, tending, and improvement.
- (5.) Approved changes.

APPENDICES.

APPENDIX I.

A. Area of circles for diameters ranging from 1 inch to 60 inches.

B. Sum of the areas of circles for diameters ranging from 1 inch to 48 inches,

or,

Volume of cylinders for diameters ranging from 1 inch to 48 inches and any length.

Example :

Find the area of 24 circles of 15 inches diameter.

		Square Feet.
Area of 20 circles	$= 10 \times 2{\cdot}4544 =$	24·544
Area of 4 circles	$=$	4·9088
	Total $=$	29·4528

or,

Find the volume of a log 24 feet long with a mean diameter of 15 inches.

		Cubic Feet.
Volume of a log 20 feet long	$= 10 \times 2{\cdot}4544 =$	24·544
Volume of a log 4 feet long	$=$	4·9088
	Total $=$	29·4528

A. AREA OF CIRCLES FOR DIAMETERS

Diam. in inches.	Area of circle in square ft.	Diam. in inches.	Area of circle in square ft.	Diam. in inches.	Area of circle in square ft.	Diam. in inches.	Area of circle in square ft.	Diam. in inches.	Area of circle in square ft.
1·0	0·0055	**2·0**	0·0218	**3·0**	0·0491	**4·0**	0·0873	**5·0**	0·1364
1	·0067	1	·0240	1	·0524	1	·0917	1	·1418
2	·0079	2	·0264	2	·0559	2	·0963	2	·1474
3	·0092	3	·0289	3	·0594	3	·1009	3	·1532
4	·0107	4	·0314	4	·0631	4	·1056	4	·1590
5	·0123	5	·0341	5	·0669	5	·1105	5	·1650
6	·0140	6	·0369	6	·0707	6	·1154	6	·1710
7	·0158	7	·0398	7	·0747	7	·1205	7	·1772
8	·0177	8	·0428	8	·0788	8	·1257	8	·1835
9	·0197	9	·0459	9	·0830	9	·1310	9	·1899
11·0	0·6600	**12·0**	0·7854	**13·0**	0·9218	**14·0**	1·0690	**15·0**	1·2272
1	·6721	1	·7986	1	·9360	1	1·0843	1	1·2437
2	·6842	2	·8118	2	·9504	2	1·0997	2	1·2602
3	·6965	3	·8252	3	·9648	3	1·1153	3	1·2768
4	·7089	4	·8387	4	·9794	4	1·1309	4	1·2936
5	·7214	5	·8523	5	·9941	5	1·1467	5	1·3104
6	·7340	6	·8660	6	1·0089	6	1·1626	6	1·3274
7	·7467	7	·8798	7	1·0237	7	1·1785	7	1·3444
8	·7595	8	·8937	8	1·0387	8	1·1946	8	1·3616
9	·7724	9	·9077	9	1·0538	9	1·2108	9	1·3789
21·0	2·4053	**22·0**	2·6398	**23·0**	2·8852	**24·0**	3·1416	**25·0**	3·4088
1	2·4283	1	2·6638	1	2·9103	1	3·1679	1	3·4361
2	2·4514	2	2·6880	2	2·9356	2	3·1942	2	3·4636
3	2·4745	3	2·7122	3	2·9610	3	3·2207	3	3·4911
4	2·4978	4	2·7366	4	2·9864	4	3·2471	4	3·5188
5	2·5212	5	2·7611	5	3·0120	5	3·2748	5	3·5465
6	2·5447	6	2·7857	6	3·0377	6	3·3006	6	3·5744
7	2·5684	7	2·8104	7	3·0635	7	3·3275	7	3·6024
8	2·5921	8	2·8352	8	3·0894	8	3·3545	8	3·6305
9	2·6159	9	2·8602	9	3·1154	9	3·3816	9	3·6587
40	8·7266	41	9·1684	42	9·6211	43	10·0847	44	10·5592
50	13·6354	51	14·1863	52	14·7480	53	15·3207	54	15·9043
60	19·6350								

The circles of full inches were calculated with logarithms

OF 1 INCH TO 60 INCHES.

Diam. in inches.	Area of circle in square ft.	Diam. in inches.	Area of circle in square ft.	Diam. in inches.	Area of circle in square ft.	Diam. in inches.	Area of circle in square ft.	Diam. in inches.	Area of circle in square ft.
6·0	0·1963	**7·0**	0·2673	**8·0**	0·3491	**9·0**	0·4418	**10·0**	0·5454
1	·2029	1	·2750	1	·3579	1	·4517	1	·5564
2	·2096	2	·2828	2	·3668	2	·4617	2	·5675
3	·2164	3	·2907	3	·3758	3	·4718	3	·5787
4	·2234	4	·2987	4	·3849	4	·4820	4	·5900
5	·2304	5	·3068	5	·3941	5	·4923	5	·6014
6	·2376	6	·3151	6	·4034	6	·5027	6	·6129
7	·2448	7	·3234	7	·4129	7	·5132	7	·6245
8	·2522	8	·3319	8	·4224	8	·5238	8	·6362
9	·2597	9	·3404	9	·4321	9	·5345	9	·6481
16·0	1·3963	**17·0**	1·5763	**18·0**	1·7671	**19·0**	1·9689	**20·0**	2·1817
1	1·4138	1	1·5949	1	1·7868	1	1·9897	1	2·2036
2	1·4314	2	1·6136	2	1·8066	2	2·0106	2	2·2256
3	1·4492	3	1·6324	3	1·8265	3	2·0316	3	2·2477
4	1·4670	4	1·6513	4	1·8465	4	2·0527	4	2·2699
5	1·4849	5	1·6703	5	1·8666	5	2·0739	5	2·2922
6	1·5030	6	1·6894	6	1·8869	6	2·0952	6	2·3146
7	1·5212	7	1·7087	7	1·9072	7	2·1167	7	2·3371
7	1·5394	8	1·7280	8	1·9277	8	2·1382	8	2·3597
9	1·5578	9	1·7475	9	1·9482	9	2·1599	9	2·3825
26·0	3·6870	**27·0**	3·9761	**28·0**	4·2761	**29·0**	4·5869	**30·0**	4·9087
1	3·7154	1	4·0056	1	4·3067	1	4·6186	31	5·2414
2	3·7439	2	4·0353	2	4·3374	2	4·6504	32	5·5851
3	3·7725	3	4·0650	3	4·3682	3	4·6823	33	5·9396
4	3·8013	4	4·0948	4	4·3991	4	4·7143	34	6·3050
5	3·8301	5	4·1248	5	4·4301	5	4·7464	35	6·6813
6	3·8591	6	4·1548	6	4·4612	6	4·7787	36	7·0686
7	3·8882	7	4·1850	7	4·4925	7	4·8110	37	7·4667
8	3·9174	8	4·2152	8	4·5238	8	4·8435	38	7·8758
9	3·9467	9	4·2456	9	4·5553	9	4·8760	39	8·2958
45	11·0447	46	11·5410	47	12·0482	48	12·5664	49	13·0954
55	16·4988	56	17·1042	57	17·7206	58	18·3478	59	18·9859

of 7 places; the intermediate values were found by interpolation.

B. TABLE OF THE SUM OF CIRCLES FOR DIAMETERS OF

Number of Circles, or, Length of Cylinder.	Diameter in Inches.							
	1	2	3	4	5	6	7	8
1	0·0055	0·0218	0·0491	0·0873	0·1364	0·1963	0·2673	0·3491
2	·0110	·0436	·0982	·1746	·2728	·3926	·5346	·6982
3	0165	·0654	·1473	·2619	·4092	·5889	·8019	1·0473
4	·0220	·0872	·1964	·3492	·5456	·7852	1·0692	1·3964
5	·0275	·1090	·2455	·4365	·6820	·9815	1·3365	1·7455
6	·0330	·1308	·2946	·5238	·8184	1·1778	1·6038	2·0946
7	·0385	·1526	·3437	·6111	·9548	1·3741	1·8711	2·4437
8	·0440	·1744	·3928	·6984	1·0912	1·5704	2·1384	2·7928
9	·0495	·1962	·4419	·7857	1·2276	1·7667	2·4057	3·1419
	17	18	19	20	21	22	23	24
1	1·5763	1·7671	1·9689	2·1817	2·4053	2·6398	2·8852	3·1416
2	3·1526	3·5342	3·9378	4·3634	4·8106	5·2796	5·7704	6·2832
3	4·7289	5·3013	5·9067	6·5451	7·2159	7·9194	8·6556	9·4248
4	6·3052	7·0684	7·8756	8·7268	9·6212	10·5592	11·5408	12·5664
5	7·8815	8·8355	9·8445	10·9085	12·0265	13·1990	14·4260	15·7080
6	9·4578	10·6026	11·8134	13·0902	14·4318	15·8388	17·3112	18·8496
7	11·0341	12·3697	13·7823	15·2719	16·8371	18·4786	20·1964	21·9912
8	12·6104	14·1368	15·7512	17·4536	19·2424	21·1184	23·0816	25·1328
9	14·1867	15·9039	17·7201	19·6353	21·6477	23·7582	25·9668	28·2744
	33	34	35	36	37	38	39	40
1	5·9396	6·3050	6·6813	7·0686	7·4667	7·8758	8·2958	8·7266
2	11·8792	12·6100	13·3626	14·1372	14·9334	15·7516	16·5916	17·4532
3	17·8188	18·9150	20·0439	21·2058	22·4001	23·6274	24·8874	26·1798
4	23·7584	25·2200	26·7252	28·2744	29·8668	31·5032	33·1832	34·9064
5	29·6980	31·5250	33·4065	35·3430	37·3335	39·3790	41·4790	43·6330
6	35·6376	37·8300	40·0878	42·4116	44·8002	47·2548	49·7748	52·3596
7	41·5772	44·1350	46·7691	49·4802	52·2669	55·1306	58·0706	61·0862
8	47·5168	50·4400	53·4504	56·5488	59·7336	63·0064	66·3664	69·8128
9	53·4564	56·7450	60·1317	63·6174	67·2003	70·8822	74·6622	78·5394

1 IN. TO 48 IN., AND OF THE VOLUMES OF CYLINDERS.

Number of Circles, or Length of Cylinder.	Diameter in Inches.							
	9	10	11	12	13	14	15	16
1	0·4418	0·5454	0·6600	0·7854	0·9218	1·0690	1·2272	1·3963
2	·8836	1·0908	1·3200	1·5708	1·8436	2·1380	2·4544	2·7926
3	1·3254	1·6362	1·9800	2·3562	2·7654	3·2070	3·6816	4·1889
4	1·7672	2·1816	2·6400	3·1416	3·6872	4·2760	4·9088	5·5852
5	2·2090	2·7270	3·3000	3·9270	4·6090	5·3450	6·1360	6·9815
6	2·6508	3·2724	3·9600	4·7124	5·5308	6·4140	7·3632	8·3778
7	3·0926	3·8178	4·6200	5·4978	6·4526	7·4830	8·5904	9·7741
8	3·5344	4·3632	5·2800	6·2832	7·3744	8·5520	9·8176	11·1704
9	3·9762	4·9086	5·9400	7·0686	8·2962	9·6210	11·0448	12·5667
	25	26	27	28	29	30	31	32
1	3·4088	3·6870	3·9761	4·2761	4·5869	4·9087	5·2414	5·5851
2	6·8176	7·3740	7·9522	8·5522	9·1738	9·8174	10·4828	11·1702
3	10·2264	11·0610	11·9283	12·8283	13·7607	14·7261	15·7242	16·7553
4	13·6352	14·7480	15·9044	17·1044	18·3476	19·6348	20·9656	22·3404
5	17·0440	18·4350	19·8805	21·3805	22·9345	24·5435	26·2070	27·9255
6	20·4528	22·1220	23·8566	25·6566	27·5214	29·4522	31·4484	33·5106
7	23·8616	25·8090	27·8327	29·9327	32·1083	34·3609	36·6898	39·0957
8	27·2704	29·4960	31·8088	34·2088	36·6952	39·2696	41·9312	44·6808
9	30·6792	33·1830	35·7849	38·4849	41·2821	44·1783	47·1726	50·2659
	41	42	43	44	45	46	47	48
1	9·1684	9·6211	10·0847	10·5592	11·0447	11·5410	12·0482	12·5664
2	18·3368	19·2422	20·1694	21·1184	22·0894	23·0820	24·0964	25·1328
3	27·5052	28·8633	30·2541	31·6776	33·1341	34·6230	36·1446	37·6992
4	36·6736	38·4844	40·3388	42·2368	44·1788	46·1640	48·1928	50·2656
5	45·8420	48·1055	50·4235	52·7960	55·2235	57·7050	60·2410	62·8320
6	55·0104	57·7266	60·5082	63·3552	66·2682	69·2460	72·2892	75·3984
7	64·1788	67·3477	70·5929	73·9144	77·3129	80·7870	84·3374	87·9648
8	73·3472	76·9688	80·6776	84·4736	88·3576	92·3280	96·3856	100·5312
9	82·5156	86·5899	90·7623	95·0328	99·4023	103·8690	108·4338	113·0976

APPENDIX II.

TABLE OF QUARTER GIRTHS IN INCHES, FEET AND SQUARED.

Inches.	Feet.	Squared.	Inches.	Feet.	Squared.	Inches.	Feet.	Squared.
¼	·0208	·0004	5¼	·437	·1914	10¼	·854	·7296
½	·0417	·0017	5½	·458	·2101	10½	·875	·7656
¾	·0625	·0039	5¾	·479	·2296	10¾	·896	·8025
1	·0833	·0069	6	·500	·2500	11	·917	·8403
1¼	·104	·0109	6¼	.521	·2713	11¼	·937	·8789
1½	·125	·0156	6½	·542	·2934	11½	·958	·9184
1¾	·146	·0213	6¾	·563	·3164	11¾	·979	·9588
2	·167	·0228	7	·583	·3403	12	1·000	1·0000
2¼	·187	·0352	7¼	·604	·3650	12¼	1·021	1·0421
2½	·208	·0434	7½	·625	·3906	12½	1·042	1·0851
2¾	·229	·0525	7¾	·646	·4171	12¾	1·063	1·1289
3	·250	·0625	8	·667	·4444	13	1·083	1·1736
3¼	·271	·0734	8¼	·687	·4727	13¼	1·104	1·2192
3½	·292	·0851	8½	·705	·5017	13½	1·125	1·2656
3¾	·313	·0977	8¾	·729	·5317	13¾	1·146	1·3129
4	·333	·1111	9	·750	·5625	14	1·167	1·3611
4¼	·354	·1234	9¼	·771	·5942	14¼	1·188	1·4102
4½	·375	·1406	9½	·792	·6267	14½	1·208	1·4601
4¾	·396	·1567	9¾	·813	·6602	14¾	1·229	1·5109
5	·417	·1736	10	·833	·6944	15	1·250	1·5625

TABLE OF QUARTER GIRTHS IN INCHES, FEET AND SQUARED.

Inches.	Feet.	Squared.	Inches.	Feet.	Squared.	Inches.	Feet.	Squared.
15¼	1·271	1·6150	20¼	1·688	2·8477	25¼	2·104	4·427
15½	1·292	1·6684	20½	1·708	2·9184	25½	2·125	4·516
15¾	1·312	1·7227	20¾	1·728	2·9900	25¾	2·146	4·605
16	1·333	1·7778	21	1·750	3·0625	26	2·167	4·694
16¼	1·354	1·8338	21¼	1·771	3·1359	26¼	2·188	4·785
16½	1·375	1·8906	21½	1·792	3·2101	26½	2·208	4·877
16¾	1·396	1·9484	21¾	1·812	3·2852	26¾	2·229	4·968
17	1·417	2·0069	22	1·833	3·3611	27	2·250	5·062
17¼	1·438	2·0664	22¼	1·854	3·4379	27¼	2·271	5·157
17½	1·458	2·1267	22½	1·875	3·5156	27½	2·292	5·251
17¾	1·479	2·1879	22¾	1·896	3·5942	27¾	2·312	5·348
18	1·500	2·2500	23	1·917	3·6736	28	2·333	5·445
18¼	1·521	2·3129	23¼	1·938	3·7539	28¼	2·354	5·541
18½	1·542	2·3767	23½	1·958	3·8351	28½	2·375	5·641
18¾	1·562	2·4414	23¾	1·979	3·9171	28¾	2·396	5·741
19	1·583	2·5069	24	2·000	4·0000	29	2·417	5·840
19¼	1·604	2·5734	24¼	2·021	4·0838	29¼	2·438	5·941
19½	1·625	2·6406	24½	2·042	4·1684	29½	2·458	6·044
19¾	1·646	2·7085	24¾	2·062	4·2539	29¾	2·479	6·145
20	1·667	2·7778	25	2·083	4·3410	30	2·500	6·250

APPENDIX III.

TABLES OF COMPOUND INTEREST.

Instead of solving the subjoined formulas with the help of logarithms, these tables convert the operations into simple multiplications.

A. *Amount* to which a capital of 1 accumulates with compound interest in n years :—

$$C_n = C_o \times 1{\cdot}0p^n.$$

Example :—C_o = £50 ; $n = 30$ years ; $p = 4$ per cent. Then—
$C_{30} = 50 \times 3{\cdot}2434 =$ £162·17.

In order to economise space, the tables give the multiplicators from 1 to 10, year by year, and afterwards only for intervals of 5 and 10 years ; hence, for intermediate years two multiplications are required. If in the above example n were $= 32$; $C_{32} = 50 \times 1{\cdot}04^{30} \times 1{\cdot}04^2 = 50 \times 3{\cdot}2434 \times 1{\cdot}0816 =$ £175·403. This holds good for all the tables.

B. *Discount,* or present value, of a capital of 1 realisable n years, hence—

$$C_o = \frac{C_n}{1{\cdot}0p^n}.$$

Example :—C_n = £80 ; $n = 40$ years ; $p = 4$ per cent ; $C_o = 80 \times {\cdot}2083 =$ £16·665.

C. *Present value* of a perpetual rental of 1 due every n years :—

$$C_o = \frac{R}{1{\cdot}0p^n - 1}.$$

Let R = £100 ; $n = 50$ years ; $p = 4$ per cent. ; $C_o = 100 \times {\cdot}1638 =$ £16·38.

D. *Present value* of a rental of 1 due at the end of every year altogether n times :—

$$C_o = \frac{R(1{\cdot}0p^n - 1)}{1{\cdot}0p^n \times {\cdot}0p}.$$

Example :—Rental R = £10 ; $n = 30$ years ; $p = 4$ per cent. ; $C_o = 10 \times 17{\cdot}2921$; C_o = £172·921.

2 PER CENT.

No. of Years.	A. $C_n = C_o \times 1{\cdot}0p^n$.	B. $C_o = \frac{C_n}{1{\cdot}0p^n}$.	C. $C_o = \frac{R}{1{\cdot}0p^n - 1}$.	D. $C_o = \frac{R(1{\cdot}0p^n - 1)}{1{\cdot}0p^n \times {\cdot}0p}$.	No. of Years.
1	1·0200	0·9804	50·0000	0·9804	1
2	1·0404	·9612	24·7525	1·9416	2
3	1·0612	·9423	16·3377	2·8839	3
4	1·0824	·9238	12·1312	3·8077	4
5	1·1041	·9057	9·6079	4·7135	5
6	1·1262	·8880	7·9263	5·6014	6
7	1·1487	·8706	6·7256	6·4720	7
8	1·1717	·8535	5·8255	7·3255	8
9	1·1951	·8368	5·1258	8·1622	9
10	1·2190	·8203	4·5663	8·9826	10
15	1·3459	·7430	2·8913	12·8493	15
20	1·4859	·6730	2·0578	16·3514	20
25	1·6406	·6095	1·5610	19·5235	25
30	1·8114	·5521	1·2325	22·3965	30
35	1·9999	·5000	1·0001	24·9986	35
40	2·2080	·4529	0·8278	27·3555	40
45	2·4379	·4102	·6955	29·4902	45
50	2·6916	·3715	·5912	31·4236	50
55	2·9717	·3365	·5072	33·1748	55
60	3·2810	·3048	·4384	34·7609	60
65	3·6225	·2760	·3813	36·1975	65
70	3·9996	·2500	·3334	37·4986	70
75	4·4158	·2265	·2928	38·6771	75
80	4·8754	·2051	·2580	39·7445	80
85	5·3829	·1858	·2282	40·7113	85
90	5·9431	·1683	·2023	41·5869	90
95	6·5617	·1524	·1798	42·3800	95
100	7·2446	·1380	·1601	43·0984	100
110	8·8312	·1132	·1277	44·3382	110
120	10·7652	·0929	·1024	45·3554	120
130	13·1227	·0762	·0825	46·1898	130
140	15·9965	·0625	·0667	46·8743	140
150	19·4996	·0513	·0541	47·4358	150
200	52·4849	·0190	·0194	49·0473	200

3 PER CENT.

No. of Years.	A. $C_o \times 1{\cdot}0p^n$.	B. $\frac{C_n}{1{\cdot}0p^n}$.	C. $\frac{R}{1{\cdot}0p^n - 1}$.	D. $\frac{R\,(1{\cdot}0p^n - 1)}{1{\cdot}0p^n \times {\cdot}0p}$.	No. of Years.
1	1·0300	0·9709	33·3333	0·9709	1
2	1·0609	·9426	16·4204	1·9135	2
3	1·0927	·9151	10·7843	2·8286	3
4	1·1255	·8885	7·9676	3·7171	4
5	1·1593	·8626	6·2785	4·5797	5
6	1·1941	·8375	5·1533	5·4172	6
7	1·2299	·8131	4·3502	6·2303	7
8	1·2668	·7894	3·7485	7·0197	8
9	1·3048	·7664	3·2811	7·7861	9
10	1·3439	·7441	2·9077	8·5302	10
15	1·5580	·6419	1·7922	11·9379	15
20	1·8061	·5537	1·2405	14·8775	20
25	2·0938	·4776	0·9143	17·4131	25
30	2·4273	·4120	·7006	19·6004	30
35	2·8139	·3554	·5513	21·4872	35
40	3·2620	·3066	·4421	23·1148	40
45	3·7816	·2664	·3595	24·5187	45
50	4·3839	·2281	·2955	25·7298	50
55	5·0821	·1968	·2450	26·7744	55
60	5·8916	·1697	·2044	27·6756	60
65	6·8300	·1464	·1715	28·4529	65
70	7·9178	·1263	·1446	29·1234	70
75	9·1789	·1089	·1223	29·7018	75
80	10·6409	·0940	·1037	30·2008	80
85	12·3357	·0811	·0882	30·6312	85
90	14·3005	·0699	·0752	31·0024	90
95	16·5782	·0603	·0642	31·3227	95
100	19·2186	·0520	·0549	31·5989	100
110	25·8282	·0387	·0403	32·0428	110
120	34·7110	0288	·0297	32·3730	120
130	46·6486	·0214	·0219	32·6188	130
140	62·6919	·0159	·0162	32·8016	140
150	84·2527	·0119	·0120	32·9377	150
200	369·3558	·0027	·0027	33·2431	200

4 PER CENT.

No. of Years.	A. $C_o \times 1{\cdot}0p^n$.	B. $\frac{C_n}{1{\cdot}0p^n}$.	C. $\frac{R}{1{\cdot}0p^n - 1}$.	D. $\frac{R(1{\cdot}0p^n - 1)}{1{\cdot}0p^n \times {\cdot}0p}$.	No. of Years.
1	1·0400	0·9615	25·0000	0·9615	1
2	1·0816	·9246	12·2549	1·8861	2
3	1·1249	·8890	8·0087	2·7751	3
4	1 1699	·8548	5 8873	3·6299	4
5	1 2167	·8219	4·6157	4·4518	5
6	1·2653	7903	3·7690	5·2421	6
7	1·3159	·7599	3·1652	6·0020	7
8	1·3686	·7307	2·7132	6·7327	8
9	1·4233	·7026	2·3623	7·4353	9
10	1·4802	·6756	2·0823	8·1109	10
15	1·8009	·5553	1·2485	11·1184	15
20	2·1911	·4564	0·8395	13·5903	20
25	2·6658	·3751	·6003	15·6221	25
30	3·2434	·3083	·4458	17·2920	30
35	3·9461	·2534	·3394	18·6646	35
40	4·8010	·2083	·2631	19·7928	40
45	5·8412	·1712	·2066	20·7200	45
50	7·1067	·1407	·1638	21·4822	50
55	8·6464	·1157	·1308	22·1086	55
60	10·5196	·0951	·1050	22·6235	60
65	12·7987	·0781	·0848	23·0467	65
70	15·5716	·0642	·0686	23·3945	70
75	18·9452	·0528	·0557	23·6804	75
80	23·0498	·0434	·0453	23·9154	80
85	28·0436	·0357	·0370	24·1085	85
90	34·1193	·0293	·0302	24·2673	90
95	41·5114	·0241	·0247	24·3978	95
100	50·5049	·0198	·0202	24·5050	100
110	74·7597	·0134	·0136	24·6656	110
120	110·6626	·0090	·0091	24·7741	120
130	163·8076	·0061	·0061	24·8474	130
140	242·4753	·0041	·0041	24·8969	140
150	358·9227	·0028	·0028	24·9303	150
200	2550·7498	·0004	·0004	24·9902	200

5 PER CENT.

No. of Years.	A. $C_0 \times 1{\cdot}0p^n$.	B. $\frac{C_n}{1{\cdot}0p^n}$.	C. $\frac{R}{1{\cdot}0p^n - 1}$.	D. $\frac{R(1{\cdot}0p^n - 1)}{1{\cdot}0p^n \times {\cdot}0p}$.	No. of Years.
1	1·0500	0·9524	20·0000	0·9524	1
2	1·1025	·9070	9·7561	1·8594	2
3	1·1576	·8638	6·3442	2·7322	3
4	1·2155	·8227	4·6402	3·5459	4
5	1·2763	·7835	3·6195	4·3295	5
6	1·3401	·7462	2·9403	5·0757	6
7	1·4071	·7107	2·4564	5·7864	7
8	1·4775	·6768	2·0944	6·4632	8
9	1·5513	·6446	1·8138	7·1078	9
10	1·6289	·6139	1·5901	7·7217	10
15	2·0789	·4810	0·9268	10·3797	15
20	2·6533	·3769	·6049	12·4622	20
25	3·3864	·2953	·4190	14·0939	25
30	4·3219	·2314	·3010	15·3725	30
35	5·5160	·1813	·2214	16·3742	35
40	7·0400	·1420	·1656	17·1591	40
45	8·9850	·1113	·1252	17·7741	45
50	11·4674	·0872	·0955	18·2559	50
55	14·6356	·0683	·0733	18·6335	55
60	18·6792	·0535	·0566	18·9293	60
65	23·8399	·0419	·0438	19·1611	65
70	30·4264	·0329	·0340	19·3427	70
75	38·8327	·0257	·0264	19·4850	75
80	49·5614	·0202	·0206	19·5965	80
85	63·2544	·0158	·0161	19·6838	85
90	80·7304	·0124	·0125	19·7523	90
95	103·0347	·0097	·0098	19·8059	95
100	131·5013	·0076	·0077	19·8479	100
110	214·2017	·0047	·0047	19·0966	110
120	348·9120	·0029	·0029	19·9427	120
130	568·3409	·0018	·0018	19·9648	130
140	1925·7674	·0011	·0011	19·9784	140
150	1507·9775	·0007	·0007	19·9867	150
200	17292·5808	·0001	·0001	19·9988	200

6 AND 7 PER CENT.

No. of Years.	6 Per Cent. A. $C_o \times 1{\cdot}0p^n$.	6 Per Cent. B. $\frac{C_n}{1{\cdot}0p^n}$.	6 Per Cent. C. $\frac{R}{1{\cdot}0p^n - 1}$.	7 Per Cent. A. $C_o \times 1{\cdot}0p^n$.	7 Per Cent. B. $\frac{C_n}{1{\cdot}0p^n}$.	7 Per Cent. C. $\frac{R}{1{\cdot}0p_n - 1}$.	No. of Years.
1	1·0600	0·9434	16·6667	1·0700	0·9346	14·2857	1
2	1·1236	·8900	8·0906	1·1449	·8736	6·9013	2
3	1·1910	·8396	5·2346	1·2250	·8163	4·4444	3
4	1·2625	·7921	3·8096	1·3108	·7629	3·2175	4
5	1·3382	·7473	2·9568	1·4026	·7130	2·4839	5
6	1·4185	·7050	2·3872	1·5007	·6663	1·9972	6
7	1·5036	·6651	1·9857	1·6058	·6227	1·6507	7
8	1·5938	·6274	1·6841	1·7182	·5820	1·3924	8
9	1·6895	·5919	1·4503	1·8385	·5439	1·1926	9
10	1·7908	·5584	1·2645	1·9672	·5083	1·0339	10
20	3·2069	·3118	0·4531	3·8697	·2584	0·3484	20
30	5·7427	·1741	·2109	7·6123	·1314	·1512	30
40	10·2840	·0972	·1077	14·9750	·0668	·0716	40
50	18·4160	·0543	·0574	29·4570	·0339	·0351	50
60	32·9790	·0303	·0313	57·9470	·0173	·0176	60
70	59·0570	·0169	·0172	113·9930	·0088	·0081	70
80	105·7600	·0095	·0095	224·2440	·0045	·0045	80
90	189·4700	·0053	·0053	441·1230	·0023	·0023	90
100	339·3120	·0029	·0030	867·7600	·0011	·0012	100
110	607·6590	·0016	·0016	1707·0230	·0006	·0006	110
120	1088·2280	·0009	·0010	3357·9920	·0003	·0003	120

6 Per Cent. D.

$$C_o = \frac{R(1{\cdot}0p^n - 1)}{1{\cdot}0p^n \times {\cdot}0p}.$$

No. of Years.	Value.	No. of Years.	Value.
1	0·9434	20	11·4699
2	1·8334	30	13·7648
3	2·6730	40	15·0463
4	3·4651	50	15·7619
5	4·2124	60	16·1611
6	4·0173	70	16·3845
7	5·5824	80	16·5091
8	6·2098	90	16·5787
9	6·8017	100	16·6175
10	7·3601	110	16·6392
..	..	120	16·6513

7 Per Cent. D.

$$C_o = \frac{R\,(1{\cdot}0p^n - 1)}{1{\cdot}0p^n - {\cdot}0p}.$$

No. of Years.	Value.	No. of Years.	Value.
1	0·9323	20	10·5928
2	1·8043	30	12·4071
3	2·6228	40	13·3300
4	3·3857	50	13·8000
5	4·0986	60	14·0371
6	4·7657	70	14·1585
7	5·3886	80	14·2200
8	5·9700	90	14·2514
9	6·5143	100	14·2685
10	7·0228	110	14·2757
..	..	120	14·2800

APPENDIX IV.

ABSTRACTS FROM BRITISH AND CONTINENTAL YIELD TABLES.

A. Tables based upon measurements made in Great Britain and Ireland :—

(1.) European larch.
(2.) Norway spruce.
(3.) Scots pine (in Scotland).

Preliminary data on—

(4.) Oregon Douglas fir.
(5.) Corsican pine.
(6.) Japanese larch.

B. Continental yield tables, given in the absence of British tables :—

(7.) Silver fir.
(8.) Oak.
(9.) Beech.
(10.) *Sūl* = *Shorea robusta*, India.

No data are as yet available for Sitka spruce.

The data refer only to timber over 3 inches diameter at the small end, for an area of one fully stocked acre.

The measurements of the volume were taken " under " bark for the British tables, and " over " bark for the Continental tables.

The British tables are prepared according to the quarter girth system ; the Continental tables give the volume in the round. To convert the latter into the former, multiply the data in them by ·785.

The British tables can be converted into metric tables by the following operations :—

Feet multiplied by ·3048 = metres.

Inches in quarter girth × 3·234 = centimetres in diameter.

Number of stems per acre × 2·471 = number of stems per hectare.

Square feet quarter girth × ·2922 = square metres per hectare.

Cubic feet quarter girth per acre × ·0891 = cubic metres per hectare.

The following number of quality classes were distinguished :—

For larch, 5 ; spruce, 5 ; Scots pine, 3 ; Douglas fir, 4 ; Corsican pine, 3 ; Japanese larch, 2 ; silver fir, 4 ; oak, 5 ; and beech, 5,

1. LARCH.

Age in Years.	Main Crop.						Thinnings.	
	Mean Height, Feet.	Mean Quarter Girth at 4′ 3″.	Number of Stems per Acre.	Basal Area, Square Feet per Acre.	Form Factor.	Volume under Bark, Cubic Feet per Acre.	Volume under Bark, per Acre.	Sum of Thinnings.
	Quality Class I. (Mean height at age of 50 = 80 feet.)							
10	18	..	..	..	..	..	..	..
20	40	4	900	98	·398	1,560	80	80
30	58	6	520	126	·397	2,900	265	345
40	71	7·5	350	140	·390	3,880	465	810
50	80	9	260	148	·386	4,570	560	1,370
60	87	10·25	205	153	·383	5,130	645	2,015
70	94	11·5	170	157	·382	5,630	615	2,630
80	100	12·25	150	159	·382	6,070	460	3,090
	Quality Class II. (Mean height at age of 50 = 70 feet.)							
10	14	..	..	..	..	..	..	..
20	31·5	3·25	1,160	82	·348	900	60	60
30	48	5	640	113	·387	2,100	210	270
40	61	6·75	410	131	·382	3,050	380	650
50	70	8·25	310	141	·375	3,700	460	1,110
60	77·5	9·5	240	148	·370	4,250	510	1,620
70	84·5	10·75	190	153	·368	4,760	525	2,145
80	90	11·75	165	156	·368	5,170	410	2,555
	Quality Class III. (Mean height at age of 50 = 60 feet.)							
10	11	..	..	..	..	..	..	..
20	26	..	..	..	..	..	..	..
30	39·5	4·25	800	100	·370	1,460	70	70
40	51	5·75	510	119	·377	2,290	235	305
50	60	7·25	370	132	·367	2,910	360	665
60	67·5	8·50	285	141	·362	3,440	400	1,065
70	74	9·75	220	147	·359	3,910	430	1,495
80	79·5	11	185	152	·356	4,300	360	1,855
	Quality Class IV. (Mean height at age of 50 = 50 feet.)							
30	31·5	3·25	1,100	84	·340	900	100	100
40	41·5	5	640	105	·360	1,570	200	300
50	50	6·25	440	120	·360	2,160	240	540
60	57·5	7·50	330	131	·353	2,660	260	800
70	64	9	255	139	·348	3,100	350	1,150
80	69·5	10	200	144	·347	3,470	325	1,475
	Quality Class V. (Mean height at age of 50 = 40 feet.)							
40	32	3·5	1,010	87	·338	940	65	65
50	40	5	620	105	·348	1,460	100	165
60	47·5	6·25	425	119	·343	1,940	215	380
70	53·5	7·50	320	128	·340	2,330	265	645
80	59	8·75	250	136	·335	2,690	285	930

2. NORWAY SPRUCE.

Age in Years.	Main Crop.						Thinnings.	
	Mean Height, Feet.	Mean Quarter Girth at 4′ 3″.	Number of Stems per Acre.	Basal Area, Square Feet per Acre.	Form Factor.	Volume under Bark, Cubic Feet per Acre.	Volume under Bark, Cubic Feet per Acre.	Sum of Thinnings.
	Quality Class I. (Mean height at age of 50 years = 80 feet.)							
10	12	..	..	..	..	..	..	..
20	31	..	..	..	..	..	..	..
30	51	5·75	710	171	·401	3,500	410	410
40	66·5	8·25	410	194	·407	5,250	925	1,335
50	80	10·50	280	211	·401	6,760	960	2,295
60	91	12·50	210	223	·395	8,020	860	3,155
70	100	14	175	231	·388	8,960	665	3,820
	Quality Class II. (Mean height at age of 50 years = 70 feet.)							
10	10·5	..	..	..	..	..	..	..
20	27	..	..	..	..	..	..	..
30	43·5	5	920	160	·408	2,840	220	220
40	58	7·5	500	189	·410	4,490	620	840
50	70	9·5	325	207	·407	5,890	700	1,540
60	79	11·5	240	220	·399	6,940	670	2,210
70	87	13·25	190	229	·392	7,800	565	2,775
	Quality Class III. (Mean height at age of 50 years = 60 feet.)							
10	9	..	..	..	..	..	..	..
20	22	..	..	..	..	..	..	..
30	36·5	4	1,310	146	·402	2,140	..	..
40	49	6·25	665	177	·424	3,680	390	390
50	60	8·25	410	198	·415	4,930	510	900
60	68	10·25	300	212	·409	5,910	540	1,440
70	75	11·75	230	224	·401	6,730	440	1,880
	Quality Class IV. (Mean height at age of 50 years = 50 feet.)							
40	40	4·75	1,000	157	·427	2,690	100	100
50	50	6·75	590	183	·426	2,900	270	370
60	56	8·5	400	201	·419	4,890	375	745
70	64	10	300	214	·410	5,660	360	1,105
	Quality Class V. (Mean height at age of 50 years = 40 feet.)							
40	31	3·5	1,500	130	·414	1,670	..	..
50	40	5·5	765	162	·435	2,820	200	200
60	47·5	7·25	500	183	·427	3,700	280	480
70	53	8·75	375	197	·422	4,400	315	795

3. SCOTS PINE (Scotland).

Age in Years.	Main Crop.						Thinnings.	
	Mean Height, Feet.	Mean Quarter Girth at 4′ 3″.	Number of Stems per Acre.	Basal Area, Square Feet per Acre.	Form Factor.	Volume under Bark of Cubic Feet per Acre.	Volume under Bark, Cubic Feet per Acre.	Sum of Thinnings.
Quality Class I. (Mean height at age of 50 years = 60 feet.)								
10	13	..	..	..	..	..	..	..
20	26	..	..	..	..	..	..	..
30	40	4·5	960	137	·354	1,940	110	110
40	51	6·25	630	165	·371	3,120	265	375
50	60	7·75	450	185	·369	4,100	330	705
60	67	9	340	197	·366	4,840	415	1,120
70	72·5	10·25	275	206	·364	5,440	485	1,605
80	77	11·5	230	212	·362	5,920	515	2,120
90	81	12·5	200	218	·360	6,350	470	2,590
100	84·5	13·25	183	223	·357	6,720	385	2,975
Quality Class II. (Mean height at age of 50 years = 50 feet.)								
10	10	..	..	..	..	..	..	..
20	20	..	..	..	..	..	..	..
30	31	3·75	1,280	116	·361	1,300	85	85
40	41·5	5·25	795	152	·393	2,480	100	185
50	50	6·75	550	174	·397	3,450	240	425
60	57	8	410	188	·396	4,250	305	730
70	62·5	9·5	325	199	·392	4,880	365	1,095
80	67	10·5	270	207	·389	5,400	395	1,490
90	71	11·5	230	213	·387	5,850	380	1,870
100	74	12·25	207	218	·384	6,200	335	2,205
Quality Class III. (Mean height at age of 50 years = 40 years.)								
10	8	..	..	..	..	..	..	..
20	16	..	..	..	..	..	..	..
30	24	..	..	..	..	..	..	..
40	32·5	4·25	1,030	130	·395	1,670	100	100
50	40	5·75	700	155	·410	2,540	110	210
60	46	7·00	510	171	·412	3,240	250	460
70	51	8·25	400	185	·404	3,810	280	740
80	55	9·25	330	194	·401	4,280	315	1,055
90	59	10·25	275	202	·398	4,750	325	1,380
100	62	11·25	237	208	·395	5,100	300	1,680

4. DOUGLAS FIR. Preliminary Yield Table.

Age in Years.	Quality Class I. At 50 Years = 110 Feet High.		Quality Class II. At 50 Years = 100 Feet High.		Quality Class III. At 50 Years = 90 Feet High.		Quality Class IV. At 50 Years = 80 Feet High.	
	Mean Height in Feet.	Volume under Bark, Cubic Feet per Acre.	Mean Height in Feet.	Volume under Bark, Cubic Feet per Acre.	Mean Height in Feet.	Volume under Bark, Cubic Feet per Acre.	Mean Height in Feet.	Volume under Bark, Cubic Feet per Acre.
10	24	..	19	..	13·5	..	9	..
20	53	2,840	44	2,030	37	1,360	29	660
30	78	5,100	68·5	4,240	59	3,380	51	2,630
40	95	6,630	86	5,800	76·5	4,950	67·5	4,150
50	110	8,000	100	7,090	90	6,170	80	5,265

5. CORSICAN PINE. Preliminary Yield Table.

Age in Years.	Quality Class I. Height = 70 Feet at 50 Years.		Quality Class II. Height = 60 Feet at 50 Years.		Quality Class III. Height = 50 Feet at 50 Years.	
	Mean Height in Feet.	Volume under Bark, Cubic Feet.	Mean Height in Feet.	Volume under Bark, Cubic Feet.	Mean Height in Feet.	Volume under Bark, Cubic Feet.
10	12	..	9	..	7	..
20	29	1,440	23·5	920	18·5	..
30	45	2,940	38	2,260	31	1,600
40	58·5	4,200	49·5	3,370	41	2,570
50	70	6,280	60	4,340	50	3,410

6. JAPANESE LARCH. Preliminary Notes.

Age in Years.	Quality Class I.		Quality Class II.	
	Mean Height.	Volume under Bark.	Mean Height.	Volume under Bark.
5	9·5	..	5·5	..
10	23·5	..	16	..
15	35	1,095	25	470
20	44·5	1,930	33	1,205
25	52	2,580	39·5	1,820

Percentage of OVER-BARK VOLUME consisting of Bark.

Quality Class.	Larch.	Spruce.	Scots Pine (Scotland).
80	18	10	..
70	19·5	10	..
60	21	10	13·5
50	22	11	15
40	22·5	12	16·5

7. Lorey's Yield Tables for **SILVER FIR**, for South Germany.

Age, Years.	Main Crop.						Thinnings.	
	Mean Height, Feet.	Mean Diameter at 4′ 3″.	Number of Stems per Acre.	Basal Area, Square Feet per Acre.	Form Factor.	Volume. Cubic Feet per Acre.	Volume, Cubic Feet per Acre.	Sum of Thinnings.
Quality Class I., or Best.								
10	3	..	..	..	..	..	..	..
20	9	1·3	..	35	..	..	..	..
30	18	2·5	..	71	·39	500	..	..
40	30	4·0	1,460	126	·45	1,700	60	60
50	45	5·6	990	171	·48	3,670	360	420
60	58	7·5	660	205	·48	5,700	570	990
70	71	9·6	460	233	·48	7,960	1,000	1,990
80	82	11·7	340	255	·49	10,350	1,290	3,280
90	91	14·2	250	273	·51	12,550	1,430	4,710
100	98	16·2	200	288	·51	14,290	1,360	6,070
110	104	17·3	180	300	·51	15,780	860	6,930
120	109	18·3	170	310	·50	16,990	710	7,640
130	112	19·1	160	320	·50	17,850	600	8,240
140	115	20·1	150	330	·50	18,840	310	8,550
Quality Class II.—III., or Average.								
10	2	..	..	..	..	..	..	..
20	6	·7	..	18	..	..	..	..
30	13	1·3	..	36	..	..	..	..
40	22	2·3	2,700	75	·39	650	..	..
50	33	3·4	2,000	127	·45	1,880	140	140
60	44	4·7	1,330	159	·50	3,530	330	470
70	55	6·2	880	182	·51	5,070	510	980
80	65	7·9	590	203	·51	6,750	740	1,720
90	73	9·8	420	220	·52	8,540	900	2,620
100	81	11·8	310	235	·53	10,140	940	3,560
110	87	13·4	250	246	·54	11,470	950	4,510
120	92	14·3	230	255	·53	12,500	750	5,260
130	96	15·1	210	262	·52	13,180	570	5,830
140	99	15·7	200	268	·52	13,830	230	6,060
Quality Class IV., or Lowest.								
10	2	..	..	..	..	..	..	..
20	5	·6	..	..	..	..	..	..
30	9	1·0	..	10	..	..	..	..
40	16	1·5	..	23	·41	150	..	..
50	24	2·4	..	86	·48	1,000	..	..
60	33	3·3	2,100	124	·49	1,990	70	70
70	42	4·2	1,480	145	·50	3,060	210	280
80	51	5·3	1,060	162	·51	4,190	400	680
90	59	6·4	780	175	·52	5,370	630	1,310
100	66	7·8	570	188	·52	6,430	790	2,100
120	76	10·4	350	205	·51	7,890	1,430	3,530

8. Wimmenauer's Yield Tables for **OAK** (Chiefly for Low Lands).

Age in Years.	Main Crop.						Thinnings.	
	Mean Height in Feet.	Mean Diameter at 4′ 3″.	Number of Stems per Acre.	Basal Area, Square Feet per Acre.	Form Factor.	Volume, Cubic Feet per Acre.	Volume per Acre, Cubic Feet.	Sum of Thinnings.
				Quality Class I., or Best.				
10	12	..	..	..	..	..	..	..
20	30	2·4	1,920	70	·27	560	..	..
30	46	4·3	820	89	·41	1,700	100	100
40	60	6·1	510	103	·48	2,930	290	390
50	71	8·2	320	115	·49	4,000	390	780
60	79	9·9	236	125	·50	4,960	440	1,220
70	86	11·4	187	133	·51	5,790	470	1,690
80	92	12·8	157	140	·51	6,530	490	2,180
90	97	14·2	133	145	·51	7,220	500	2,680
100	101	15·3	114	149	·52	7,800	500	3,180
110	105	16·9	98	153	·52	8,320	490	3,670
120	108	18·4	85	157	·52	8,790	490	4,160
130	111	19·6	76	160	·52	9,220	460	4,620
140	113	21·0	68	163	·52	9,620	460	5,080
150	115	22·3	61	166	·52	10,010	440	5,520
				Quality Class III., or Average.				
10	10	..	..	..	..	..	..	..
20	21	1·7	3,590	57	·08	100	..	..
30	32	3·0	1,185	75	·32	700	..	..
40	43	4·5	820	91	·42	1,630	90	90
50	52	6·1	510	103	·47	2,520	200	290
60	60	7·4	370	112	·49	3,260	270	560
70	67	8·9	280	120	·49	3,940	310	870
80	72	10·1	230	127	·50	4,600	320	1,190
90	77	11·4	190	134	·50	5,200	340	1,530
100	81	12·5	160	139	·51	5,770	350	1,880
110	85	13·7	140	144	·51	6,290	360	2,240
120	89	15·0	120	148	·51	6,750	360	2,600
130	92	16·2	105	151	·52	7,170	360	2,960
140	95	17·4	93	154	·52	7,570	350	3,310
150	98	18·4	85	156	·52	7,960	330	3,640
				Quality Class V., or Lowest.				
10	5	..	..	..	..	..	..	..
30	19	1·8	3,300	59	..	..	..	..
50	33	3·9	1,010	85	·35	990	30	30
60	39	5·1	670	96	·41	1,540	100	130
70	45	6·3	480	104	·45	2,120	130	260
80	51	7·4	380	112	·47	2,670	160	420
90	56	8·4	310	118	·48	3,200	190	610
100	60	9·4	255	124	·50	3,690	210	820
110	64	10·4	220	129	·50	4,140	230	1,050
120	68	11·4	190	134	·50	4,570	230	1,280
130	71	12·4	165	139	·51	4,990	230	1,510

9. SCHWAPPACH'S YIELD TABLES FOR **BEECH** IN NORTH GERMANY.

Years.	Main Crop.						Thinnings.	
	Mean Height, Feet.	Mean Diameter at 4′ 3″.	Number of Stems per Acre.	Basal Area, Square Feet per Acre.	Form Factor.	Volume, Cubic Feet per Acre.	Volume, Cubic Feet per Acre.	Sum of Thinnings.
				QUALITY CLASS I., OR BEST.				
10	6	..	..	..	..	..	..	..
20	18	1·7	2,550	40	..	..	..	..
30	31	3·0	1,550	74	·30	690	..	..
40	45	4·5	940	105	·41	1,940	130	130
50	56	6·3	600	131	·45	3,330	400	530
60	67	8·0	423	148	·46	4,370	590	1,120
70	76	9·5	316	156	·48	5,640	740	1,860
80	85	10·9	249	161	·48	6,560	830	2,690
90	92	12·2	201	165	·48	7,360	830	3,520
100	98	13·5	166	166	·49	8,050	960	4,380
110	104	14·6	142	167	·50	8,630	840	5,220
120	107	15·6	126	166	·51	9,120	830	6,050
130	110	16·5	112	165	·52	9,520	830	6,880
140	113	17·3	100	165	·53	9,850	820	7,700
				QUALITY CLASS III., OR AVERAGE.				
10	5	..	..	..	..	..	..	..
20	13	1·3	..	28	..	..	..	..
30	23	2·2	2,070	53	·07	90	..	..
40	33	3·3	1,390	81	·35	940	..	..
50	43	4·4	970	104	·45	2,000	90	90
60	52	5·5	930	121	·46	2,920	270	360
70	60	6·4	580	131	·47	3,720	330	690
80	67	7·4	460	137	·48	4,430	360	1,050
90	73	8·3	370	138	·49	4,960	460	1,510
100	79	9·2	300	138	·49	5,340	560	2,070
110	84	10·0	250	136	·49	5,620	600	2,670
120	88	10·9	210	135	·49	5,860	570	3,240
130	91	11·8	175	134	·49	6,070	530	3,770
140	93	12·7	150	132	·51	6,260	490	4,260
				QUALITY CLASS V., OR LOWEST.				
10	3	..	..	..	..	..	..	..
20	7	·9	..	18	..	..	..	..
30	13	1·6	..	34	..	..	..	..
40	20	2·3	2,000	57	·35	400	..	..
50	28	3·1	1,510	80	·42	930	..	..
60	34	3·7	1,200	98	·46	1,530	..	..
70	39	4·4	1,000	108	·48	2,040	..	..
80	44	5·0	830	115	·48	2,410	70	70
90	47	5·5	700	117	·49	2,670	130	200
100	50	6·0	610	118	·49	2,860	150	350
120	54	6·7	470	116	·49	3,030	330	680
140	57	7·3	390	114	·50	3,220	290	970

10. Smythies' and Howard's Yield Tables for SĀL (*Shorea robusta*).

Age, Years.	Main Crop.						Thinnings.	
	Mean Height, Feet.	Mean Diameter at 4·5″.	Number of Stems per Acre.	Basal Area, Square Feet per Acre.	Form Factor.	Volume, Cubic Feet per Acre.	Volume, Cubic Feet per Acre.	Sum of Thinnings.
Quality Class I. (Maximum height over 110 feet.)								
20	51	6·0	433	85	·417	1,810	1,120	1,120
30	67	8·7	257	107	·423	3,030	820	1,940
40	79	11·2	180	123	·427	4,150	820	2,760
50	90	13·2	137	132	·411	4,880	770	3,530
60	98	15·2	108	136	·408	5,440	690	4,220
70	106	16·8	89	137·5	·410	5,980	645	4,865
80	111·5	18·5	74	138·5	·415	6,405	610	5,475
90	116·5	20·1	63	139	·421	6,810	580	6,055
100	120	21·6	55	139·5	·429	7,170	565	6,620
Quality Class II. (Maximum height between 110—90 feet.)								
20	40	4·2	780	77	·316	970	600	600
30	53	6·4	390	87	·383	1,765	600	1,200
40	63·5	8·7	252	104	·423	2,800	600	1,800
50	72	10·8	184	116	·418	3,490	560	2,360
60	80	12·5	145	123	·399	3,930	545	2,905
70	87	14·0	118	126	·398	4,360	540	3,446
80	92	15·4	98	127	·403	4,710	515	3,960
90	96·5	16·8	82	127	·413	5,065	470	4,430
100	100	18·1	71	127	·423	5,375	460	4,890
Quality Class III. (Maximum height between 90—70 feet.)								
20	31	2·5	..	52	·149	240	..	..
30	43	4·5	652	72	·349	1,080	440	440
40	51	6·7	359	88	·415	1,860	440	880
50	59	8·6	250	101	·427	2,540	445	1,325
60	65	10·2	192	109	·398	2,820	320	1,645
70	69	11·6	154	113	·387	3,015	365	2,010
80	73	12·8	128	114	·391	3,255	375	2,385
90	76	14·0	107	114	·402	3,480	360	2,745
100	78	15·2	90	114	·415	3,690	335	3,080

The above yield tables refer only to the United Provinces. The volume refers to timber down to 2 inch diameter, but the trees were measured at 4·5 feet from the ground, instead of 4·25 ft., as is done in Europe.

APPENDIX V.

General Working Plan of a High Forest of Beech

A.—Allotment of Woods to the several

Compartment.	Area in Acres.	Present Age.	Final Age *before* Shifting.	Allotment of Woods to Periods Before Shifting. I. Period. Acres.	II. Period. Acres.	III. Period. Acres.	IV. Period. Acres.	V. Period. Acres. With Overwood.	V. Period. Acres. Without Overwood.
1	19	80	110		19				
2	8	60	110			8			
3	6	60	110			6			
4	11	40	110				11		
5	9	15	105					6	3
6	3	130	140	3					
7	7	10	100					7	
8	9	50	100			9			
9	4	75	105		4				
10	11	75	105		11				
11	9	75	105		9				
12	13	75	105		13				
13	3	80	110		3				
14	7	16	106						7
15	7	16	106						7
16	7	65	95		7				
17	4	70	100		4				
18	5	70	100		5				
19	5	75	105		5				
20	10	82	92	10					
21	3	13	103						3
Total	160			13	80	23	11	13	20
								33	

Total Area = 160 acres. Average per Period = 32 acres.

with a Moderate Admixture of Oak, Ash, and Conifers.

PERIODS ACCORDING TO **AREA**.—Rotation = 100 Years.

Com-part-ment.	Final Age *after* Shifting.	Allotment of Woods to Periods **After** Shifting.						Remarks.
		I. Period. Acres.	II. Period. Acres.	III. Period. Acres.	IV. Period. Acres.	V. Period. Acres. With Over-wood.	V. Period. Acres. With-out Over-wood.	
1	130			19				Shifted, as the wood is of good growth, to relieve II. Period.
2	110			8				
3	130				6			Shifted, to fill up IV. Period.
4	110				11			
5	105					6	3	
6	140	3						
7	100					7		
8	120				9			Shifted, to fill up IV. Period.
9	145				4			
10	105		11					
11	105		9					
12	85	13						Shifted, to provide for I. Period.
13	90	3						Shifted, to provide for I. Period.
14	106						7	
15	106						7	
16	95 & 115		3·5	3·5				
17	100		4					
18	100		5					
19	85	5						Shifted, to provide for I. Period.
20	92	10						
21	103						3	
		34	32·5	30·5	30	13	20	
						33		

Lists of Woods already under Regeneration, and

Serial Number.	Compartment.	Area, Acres.	Species.	Age.		Trees to be Left as Standards.	
				Present.	At the Time of Cutting (mean).	Species.	No.
						1. Woods already under	
1	5	9	Beech	104	107	Oak	16
			Scots Pine	104	107		
2	7	7	Beech	116	119		
	Total	16					
						2. Woods to be Cut and Regenerated	
1	6	3	Beech	130	140	Oak	3
2	12	13	Beech	75	85		
			Oak	71	81	Oak	150
			Conifers	70	80		
3	13	3	Beech	80	90	Oak	11
4	19	5	Beech	75	85		
5	20	10	Beech	82	92	Oak	54
			Scots Pine	82	92		
	Total	34					

Woods to be taken under Regeneration during the I. Period.

Serial Number.	Yield in Solid Cubic Feet. Estimate. Present Volume.	Increment.	Total.	Mean per Acre.	Actual Result.	Regeneration. Natural, Acres.	Artificial. Manner of Formation.	Species.	Area, Acres.	Remarks.
Regeneration.										
1	5,238 232	151 7	5,389 239	625		5	Planting	Oak Spruce	4	Increment $\frac{5238}{104} \times 3 =$ 151 cub. ft. $\frac{232}{104} \times 3 =$ 7 cub. ft.
2	8,091	209	8,300	1,186		4·50	Planting	Oak Ash Spruce	2·50	$\frac{8091}{116} \times 3 =$ 209 cub. ft.
	13,561	367	13,928			9·50			6·50	
during the I. Period.										
1	19,827	1,525	21,352	7,117		2	Sowing	Oak	1	Increment. $\frac{19,827}{130} \times 10$ =1,525 cub. ft.
2	33,237 4,444 706	4,432 626 101	37,669 5,070 807	3,350		8	Sowing	Scots Pine Larch Spruce	5	etc.
3	14,575	1,822	16,397	5,466		2	Sowing	Oak	1	
4	30,400	4,053	34,453	6,891		3	Planting	Oak Larch	2	
5	36,279 1,384	4,422 169	40,701 1,553	4,225		6	Planting	Larch Spruce Scots Pine	4	
	140,852	17,150	158,002	4,647		21			13	

Calculation of Yield for the I. Period.

Sources of Yield.	Solid Cubic Feet.			
	Yield.		Grand Total.	Mean Annual Yield.
	Detailed.	Total.		
a. Thinnings* say . . .	50,000			
b. Other intermediate yields .	..	50,000	50,000	2,500
c. Balance in woods already under regeneration . . .	13,928	13,928		
d. Final yield of woods to be regenerated	158,002			
† To be deducted as remaining to be carried over into the II. period.	24,552			
e. Balance of *d* to be cut . .		133,450		
f. Total of *c.* and *e* . . .			147,378	7,369
Total of all yields . .			197,378	9,868

* See next page.

† The calculation is made as follows:—Regeneration period = 10 years; mean volume per acre of woods in I. period = 4,647 cubic feet. There remain, when the seeding cutting has been made = 4,647 × ·6 = 2,788, say, 2,790 cubic feet. It is assumed that these 2,790 cubic feet are cut away in annually equal instalments of $\frac{1}{10}$th, = 279 cubic feet; hence, the ten coupes, each of $\frac{160}{10}$ = 1·6 acres, will, at the end of the I. period, have volumes per acre equal to:

Coupe 10 = 2,790.	Coupe 9 = 2,511.	Coupe 8 = 2,232.
,, 7 = 1,953.	,, 6 = 1,674.	,, 5 = 1,395.
,, 4 = 1,116.	,, 3 = 837.	,, 2 = 558.
,, 1 = 279.		

thus forming an arithmetical series, the sum of which is $= (2{,}790 + 279) \times \frac{10}{2} = 15{,}345$.

This sum must be multiplied by 1·6, the size of the coupe, making the volume to be carried forward into the II. period = 15,345 × 1·6 = 24,552 cubic feet.

Local Yield Table for Thinnings.

Age Class.	Yield of Thinnings c′ solid per acre.
21— 30	170
31— 40	200
41— 50	230
51— 60	245
61— 70	260
71— 80	230
81— 90	200
91—100	155

This table has been used to calculate the expected yield of thinnings during the next 20 years. The full details have been omitted ; the total volume amounts to 50,000 cubic feet in round figures.

Examples.—Taking Compartment 1, now 80 years old, the thinnings would amount, during the next ten years, to

$$19 \times 200 = 3{,}800 \text{ cubic feet.}$$

In the case of Compartment 9, now 75 years old:

$$\text{For the first 5 years} = 4 \times \frac{230}{2} = 460 \text{ cubic feet}$$

$$\text{For the second 5 years} = 4 \times \frac{200}{2} = 400 \quad ,,$$

$$\text{Total} = 860 \text{ cubic feet.}$$

B.—General Working Plan for the Method by VOLUME,

THE FINAL YIELD HAS BEEN TAKEN FROM THE YIELD

Compartment.	Area in Acres.	Present Age.	Final Age *before* Shifting.	Final Yield per Acre *before* Shifting.	ALLOTMENT OF FINAL YIELD IN *C′* **Before** SHIFTING.				
					I. Period.	II. Period.	III. Period.	IV. Period.	V. Period.
1	19	80	110	6,590		125,210			
2	8	60	110	6,590			52,720		
3	6	60	110	6,590			39,540		
4	11	40	110	6,590				72,490	
5	9	15	105	6,455					58,095
6	3	130	140	7,300	21,900				
7	7	10	100	6,320					44,240
8	9	50	100	6,320			56,880		
9	4	75	105	6,455		25,820			
10	11	75	105	6,455		71,009			
11	9	75	105	6,455		58,095			
12	13	75	105	6,455		83,915			
13	3	80	110	6,590		19,770			
14	7	16	106	6,482					45,374
15	7	16	106	6,482					45,374
16	7	65	95	6,125		42,875			
17	4	70	100	6,320		25,280			
18	5	70	100	6,320		31,600			
19	5	75	105	6,455		32,275			
20	10	82	92	6,008	60,080				
21	3	13	103	6,401					19,203
Total	160				81,980	515,849	149,140	72,490	212,286

Grand total of yield = 1,031,745 cubic feet.
Average per period = 206,349 ,,

based upon the data given in the Table at pages 364—65.

TABLE FOR BEECH, III. QUALITY, INCLUDING FUEL.

Compartment.	Final Age *after* Shifting.	Final Yield per Acre *after* Shifting.	ALLOTMENT OF FINAL YIELD IN C' After SHIFTING.				
			I. Period.	II. Period.	III. Period.	IV. Period.	V. Period.
1	130	7,090			134,710		
2	110	6,590			52,720		
3	130	7,090				42,510	
4	110	6,590				72,490	
5	105	6,455					58,095
6	140	7,300	21,900				
7	100	6,320					44,240
8	120	6,840				61,560	
9	145	7,405				29,620	
10	105	6,455		71,009			
11	105	6,455		58,095			
12	85	5,665	73,645				
13	90	5,930	17,790				
14	106	6,482					45,374
15	106	6,482					45,374
16*	95 & 115	6,125 & 6,715		21,437	23,502		
17	100	6,320		25,280			
18	100	6,320		31,600			
19	85	5,665	28,325				
20	92	6,008	60,080				
21	103	6,401					19,203
Total . .			201,740	207,421	210,932	206,180	212,286

Grand total of yield	=	1,038,559.
Average per period	=	207,712.
Average annual yield in I. period	=	10,087.
,, ,, ,, V. ,,	=	10,614.

* Half of the compartment will be cut in the II. period, and the other half in the III. period.

APPENDIX VI.

General Working Plan drawn up according

Rotation,

Compartments.	Distribution of Age							
	1—40 years old.		41—60.		61—80.		81—100.	
Number.	Cubic feet.	Acres.	Cubic feet.	Acres.	Cubic feet.	Acres.	Cubic feet.	Acres.
1	48,030	41	70,630	20				
2	200,945	117	169,514	40	192,117	40	15,892	2
3	19,072	34						
4	21,189	38						
5								
6	109,479	87	201,299	37	423,787	67	353,156	49
7	26,487	24	46,617	11	25,074	5	494,418	49
8	28,605	51			35,316	5	42,379	5
9	13,420	48						
Total . .	467,227	440	488,060	108	676,294	117	905,845	105
Normal state under a rotation of 120 years								
Comparison of real and normal state + —								

Calculation of the Yield.

This is done according to the formula :—

$$\text{Annual yield} = I_{real} + \frac{G_{real} - G_{normal}}{a}.$$

The real increment, I_{real} = 102,696 cubic feet.
The real growing stock, G_{real} = 8,939,771 ,, ,,
The normal growing stock, G_{normal} = 7,456,200 ,, ,,

The surplus of growing stock = 1,483,571 cubic feet.

Assuming that this surplus is to be removed in the course of 50 years, the yield would be—

$$\text{Annual yield} = 102{,}696 + \frac{1{,}483{,}571}{50} = 102{,}696 + 29{,}671$$
$$= 132{,}367,$$

or, during the first 10 years = 1,323,670 cubic feet.

to the Austrian Assessment Method.

120 Years.

Classes.					Volume per Acre, Cubic Feet.	Increment.			
Compartments.	Over 100 Years.		Total.			Annual, per acre.		Total in 10 Years.	
Number.	Cubic feet.	Acres.	Cubic feet.	Acres.		Normal.	Real.	Normal.	Real.
1	34,250	4	152,910	65	2,352	85	70	55,250	45,500
2	118,662	12	697,130	211	3,304	85	75	179,350	158,250
3	381,408	37	400,480	71	5,641	70	61	49,700	43,310
4	1,606,861	148	1,628,050	186	8,753	85	71	158,100	132,060
5	1,522,104	133	1,522,104	133	11,444	100	71	133,000	94,430
6	540,329	43	1,628,050	283	5,753	100	78	283,000	220,740
7	365,870	49	958,466	138	6,945	85	85	117,300	117,300
8	459,103	34	565,403	95	5,952	100	71	95,000	67,450
9	1,373,758	124	1,387,178	172	8,365	100	86	172,000	147,920
	6,402,345	584	8,939,771	1,354	6,603		76		1,026,960
			7,456,200		5,507	92		1,242,700	
			1,483,571		1,096		16		215,740

The yield for the next 10 years having been fixed, the forester decides where it is to be cut. He selects in the first place all silvicultural necessities, such as severance cuttings, the removal of shelter trees over young regeneration ; next he adds all woods which are poor in increment, especially those which have suffered from natural phenomena ; finally he makes up the total yield by adding the oldest woods, with due consideration of a proper distribution of the age classes over the area. In this way, the Special Working Plan on the next two pages has been obtained.

A detailed record of the work done in each compartment is kept (see page 378) ; from these data, and those on pages 374—75, the Summary on pages 376—77 is prepared, which compares the provisions of the working plan with the actual results.

Special Working Plan.

Compartments.	Description of Cuttings, Cultivation, etc.	Cuttings. Final. Cubic Feet.	Cuttings. Intermediate. Cubic Feet.	Cultivation. Acres.	Draining, Ditches. Feet.	Road Construction. Feet.
1.	Final cutting in regenerated part	34,000				
	Filling up blanks with spruce			3		
	Thinning, and cutting cancerous silver firs . .		10,000			
	Total . . .	34,000	10,000	3		
2.	*a. Thinning of shelter-wood and partial final cutting.	35,000				
	Filling up blanks with spruce and Scots pine . . .			10		
	a & b. Thinning and removal of cancerous trees . .		53,000			
	Total . . .	35,000	53,000	10		
3.	a. Seeding cutting, and partly final cutting . . .	53,000				
	b & c. Rest.					
	Total . . .	53,000				
4.	a. Thinning of shelter-wood, Seeding cutting in the fully stocked parts by the removal of cancerous and large trees .	341,000				
	b. Rest.					
	Total . . .	341,000				
5.	a. Thinning and removal of cancerous trees . . .	19,000	19,000			
	b & c. Rest.					
	Construction of an export road to meet the main road . .					4,900
	Total . . .	19,000	19,000			4,900

* *a*, *b*, *c* refer to sub-compartments.

Special Working Plan—*continued.*

Compartments.	Description of Cuttings, Cultivation, etc.	Cuttings. Final. Cubic Feet.	Cuttings. Intermediate. Cubic Feet.	Cultivation. Acres.	Draining Ditches. Feet.	Road Construction. Feet.
6.	*a.* Cutting of all old standards and cancerous trees . .	45,000				
	Thinning		3,000			
	b. Thinning of shelter-wood and partially final cutting . .	198,000				
	Filling up blanks with spruce.			12		
	c. Cutting out of old defective trees where young growth exists	14,000				
	Construction of an export road to meet the main road .					9,500
	Total . . .	257,000	3,000	12		9,500
7.	*a.* Thinning and removal of cancerous trees . . .	47,000	47,000			
	b. Rest.					
	c. Removal of standards and cancerous trees . . .	25,000				
	Thinning		15,000			
	Construction of an export road.					5,000
	Total . . .	72,000	62,000			5,000
8.	In the regeneration area: thinning of shelter-wood and partially final clearing; in the rest seeding cutting .	163,000				
	Filling up blanks with spruce .			3		
	Construction of an export road.					3,500
	Total . . .	163,000		3		3,500
9.	Continuation of regeneration cuttings and removal of cancerous trees	195,000				
	Thinning in fully stocked parts.		7,000			
	Filling up blanks with spruce and Scots pine . .			8		
	Construction of an export road					3,000
	Total . .	195,000	7,000	8		3,000

Summary of the Provisions of the

Compartments.	Provisions of Working Plan.					
	Cuttings.			Cultivation. Acres.	Draining. Feet.	Road Construction. Feet.
	Final. Cubic Feet.	Intermediate. Cubic Feet.	Total. Cubic Feet.			
1.	34,000	10,000	44,000	3		
2.	35,000	53,000	88,000	10		
3.	53,000		53,000			
4.	341,000		341,000			
5.	19,000	19,000	38,000			4,900
6.	257,000	3,000	260,000	12		9,500
7.	72,000	62,000	134,000			5,000
8.	163,000		163,000	3		3,500
9.	195,000	7,000	202,000	8		3,000
Total ..	1,169,000	154,000	1,323,000	36		25,900

Note.—The excess was due to heavy windfalls; it will not derange future

Working Plan and of the Execution.

Compartments.	Results of Actual Work Done.						Comparison of Proposed and Executed Cuttings.		Remarks.
	Cuttings.			Cultivation. Acres.	Draining. Feet.	Road Construction. Feet.	Cut too much. Cubic Feet.	Cut too little. Cubic Feet.	
	Final. Cubic Feet.	Intermediate. Cubic Feet.	Total. Cubic Feet.						
1.	33,034	12,549	45,583	4·4			1,583		
2.	54,517	75,000	129,517	5·0			41,517		Excess due to windfalls and snow-break.
3.	132,900		132,900	·1			79,900		Excess due to windfalls and snow-break.
4.	177,169		177,169	·1				163,831	Held back, on account of extra fellings in other compts.
5.	86,606	68,301	154,907			5,003	116,907		Excess due to windfalls.
6.	342,444	21,635	364,079	8·4		9,679	104,079		Excess : windfalls.
7.	95,852		95,852			5,299		38,148	Thinning held over.
8.	111,049		111,049	·9		3,691		51,951	Held back on account of excess in other compts.
9.	197,660		197,660			2,953		4,340	
Total	1,231,231	177,485	1,408,716	18·9		26,625	85,716		

arrangements, as there is a considerable excess of growing stock in the forest.

Sample Page of the Detailed Control Book.

Compartment 1.

Year.	Description of Cuttings, Cultivation, etc.	Cuttings.		Cultivation. Acres.	Draining Ditches. Feet.	Road Construction. Feet.
		Final. Cubic Feet.	Intermediate. Cubic Feet.			
Provision of Working Plan.						
	Final cutting in regenerated part .	34,000				
	Filling up blanks with spruce .			3		
	Thinning and cutting of cancerous silver firs		10,000			
	Total . . .	34,000	10,000	3		
Execution.						
1884	Final cutting	14,297				
,,	Dry and windfall wood . .	813				
1885	Windfalls	665				
1886	Final cutting, thinning . .	6,166	832			
,,	Windfalls	547				
1887	Windfalls	1,363				
1888	Final cutting, thinning . .	7,759	11,717			
,,	Planting			1·7		
,,	Windfalls	82				
1889	Dry wood, windfalls . . .	649				
,,	Planting			2·2		
1890	Windfalls	693				
,,	Planting			·1		
1891	Planting			·2		
1892	Planting			·1		
1893	Planting			·1		
	Total . . .	33,034	12,549	4·4		

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END OF VOLUME III.

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